

University of Cape Town

Faculty of Humanities

Practical science process skills in physics, with special reference to test  
item assessment and classification

A dissertation submitted to the University of Cape Town in fulfilment of the  
requirements for the degree of  
MASTER OF EDUCATION

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## TABLE OF CONTENTS

Acknowledgements	I
Abstract	II
List of tables	IV
List of figures	VII
List of appendices	VIII
List of abbreviations	IX

### Chapter 1: INTRODUCTION

✓ 1.1	Background and context of the study	1
✓ 1.2	Statement of the problem, purpose and key questions, and conceptual framework	3
✓ 1.3	Origin and purpose of the problem	7
✓ 1.4	Importance, significance and value of the study	10
1.5	The nature of the problem: issues of assessment	14
1.6	Clarification of terms	17
1.7	Delineation of the research	18
✓ 1.8	Assumptions of the study	19
1.9	Research approach	19
✓ 1.10	List of dependent and independent variables	20
	1.10.1. Dependent variables for each participant	20
	1.10.2. Independent variables for each participant	20
1.11	Hypotheses	20
1.12	Chapter summary	21
1.13	Organization of the remainder of the dissertation	21 21

### CHAPTER 2: LITERATURE REVIEW

2.1	Science process skills	23
2.2	The skills and aims of practical work	29
2.3	Science process skills and the theory of White (1988)	37
2.4	Scientific literacy and technological literacy and the public	✓



understanding of science	40
2.5 Studies of scientific literacy ✓	50
2.6 Specific content areas of science teaching	55
2.6.1 Electricity: cells, resistors, bulbs, current, voltage, wattage, circuits etc.	55
2.6.2 Mechanics	58
2.6.3 Optics	60
2.6.4 Discussion	60
2.7 Methods of teaching everyday science	61
2.8 Assessment in science teaching ✓	65
2.9 Teacher training and science practical work	70
2.10 Gender issues in science learning and achievement	72
2.11 The intelligence theory of Franus, and scientific thought systems	74
2.12 The intelligence theory of Gardner, and scientific thought systems	76
2.13 Chapter summary	79

25

### CHAPTER 3 RESEARCH METHODOLOGY

56 1293

3.1 The sample groups of respondents	80
3.2 Research methodology	83
3.2.1 Survey research method	83
3.2.2 Administration of the practical test items	84
3.2.3 Initial and final selection of the core items and practical activities	85
3.3 Data collection sheets	93
3.3.1 The quantitative data collection	93
3.3.2 The qualitative data collection	96
3.4 Pilot trial refinements during phase 1	98
3.5 Treatment of the data collected	102
3.5.1 Treatment of the quantitative data	102
3.5.2 The qualitative data: proposed methods of treatment and analysis	104
3.6 Null hypotheses	104
3.7 Chapter summary	107

net - 2  
3083

## CHAPTER 4 PRESENTATION AND ANALYSIS OF RESULTS

4.1	Section A: The compact programme: its basic statistical properties and parameters	110
4.2	Section B: Presentation of the quantitative findings: hypothesis testing	116
4.2.1	Academic level of school/institution as an independent variable	116
4.2.2	Gender as an independent variable	118
4.2.3	Grade level of the participants as an independent variable	120
4.2.4	The test items' specified inclusion in the matriculation syllabus as an independent variable	121
4.2.5	English proficiency as an independent variable	122
4.2.6	The participants' schools/institutions as an independent variable	125
4.2.7	Participants' degree of familiarity with the apparatus as a correlate	128
4.2.8	Summary of achievements of different samples	130
4.3	Section C: Presentation of the qualitative findings	130
4.3.1	Affective responses to the tasks	131
4.3.2	Process skill responses	133
4.3.3	The perceived value of the programme for learning	136
4.3.4	The difficulty of the practical items	137
4.3.5	The personal demands and enthusiasm of participants for practical assessment and practical science tasks	137
4.3.6	Science as a school subject	138
4.3.7	Summary	138
4.4	Section D: Evaluation of the design, context and structure of the compact programme in terms of eight different theories of practical work	140
4.5	Section E. Evaluation of the final version of the compact programme in terms of standard test item construction criteria	146
4.6	Chapter summary	147

80 pgs in all

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## **CHAPTER 5 DISCUSSION OF RESULTS AND FINDINGS**

5.1	Purpose no.1: To gather evidence to establish the extent to which the 13 process skills listed in the Revised National Curriculum Statement Draft (2001) are tested by the 17 practical activities in the compact programme.	148
5.2	Purpose no.2: To develop and discuss a practical programme of activities and items which meet the criteria for test item construction.	154
5.3	Purpose no.3: To discuss the appropriateness of the Western Cape Education Department (WCED) Assessment Workbook criteria.	155
5.4	Purpose no.4: How well does the programme meet the 35 Revised National Curriculum Statement Draft (2001: 4; 7; 10; 14-16) criteria?	156
5.5	Purpose no.5: To determine and discuss the programme performance scores of different groups of participants in different contexts at different levels of development.	157
5.6	Purpose no.6: To determine the usefulness, relevance of and enthusiasm for the programme by different interest groups.	169
5.7	Purpose no.7: To determine and discuss a perceived relevant match or a perceived “irrelevant” mismatch between the science process skills tested by the current experimental programme of practical items and the descriptive theories of practical science and its classification schemes and criteria.	171
5.8	Purpose no.8: Recommendations for teaching practical physics	179
5.9	Purpose no.9: To discuss more deeply and thoroughly how physics practical work should be assessed.	182
5.10	Purpose no.10: Evidence disclosing weaknesses in the research design of the dissertation	188
5.11	Chapter Summary	189

81 page

## **CHAPTER 6 CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS**

6.1	Question 1: Which of the 13 process skills listed in the Revised National Curriculum Statement Draft (2001:99-100) are tested/encouraged by the practical items in the compact programme?	190
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6.2	Question 2: Do the practical items deployed in this study contain additional worthwhile process skills that are not in the Revised National Curriculum Statement Draft (2001:99-100)	193
6.3	Question 3: After repeated phase 1 field trials to improve the presentation of the apparatus, wording, content and process tasks incorporated into each individual practical item, (and also incorporated into the performance programme as a whole in its final form), do the ten items also meet the following standard criteria for test item construction?	194
6.4	Question 4: Do the practical tasks satisfy the following additional criteria advocated by the Western Cape Education Department (WCED) Assessment Workbook (May 2001:4) and by the Revised National Curriculum Statement Draft (2001:73)?	196
6.5	Question 5: During the eleven phase 1 field trials to improve the apparatus, wording, content and process tasks incorporated into each individual practical item, and into the performance programme as a whole in its final form, does the programme of task items also meet the 37 curriculum criteria advocated by the Revised National Curriculum Statement Draft (2001: 4; 7; 10; 14-16)	197
6.6	Achievements of the sample groups of participants	200
6.7	Classification frameworks	202
6.8	Further research	205
6.9	Final conclusion	206

206.  
1910

and 15 pgs

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## ABSTRACT

This study describes the development, validation, classification, administration and assessment of a compact programme of ten core practical task items chosen from a pool of 33 practical tasks developed for the purpose of this study in basic school physical science. The practical items encouraged and measured various science process skills laid out in the South African Revised National Curriculum Statement Draft.

The derivation and classification of the specially designed diagnostic practical task items by experienced lecturers, teachers and academics constitutes an original and crucial part of the study. The objective is to assess the consensus of juries of four to eleven expert science educators on classification of the ten core practical activities, matching the categories. The investigation establishes whether there is a perceived relevant match or a perceived “irrelevant” mismatch between the science process skills tested by the current experimental programme of practical items and the descriptive theories of practical science and its classification schemes and criteria proposed by (a) Franus (1992), (b) Gardner (1983), (c) White (1988), (d) Solomon (1998), (e) Lock (1990), (f) Kapenda, Kandjeo-Marenga, Gaoseb, Kasanda and Lubben’s (2001) the Cambridge-based International General Certificate of Education after Millar, le Marechal and Tiberghiea (1999), (g) Race (1997) and (h) OBE (Revised National Curriculum Statement Draft, 2001). Lock’s assessment framework for practical tasks was found to be the most relevant scheme among the others. The study also identified eight process skills that are highly relevant to practical tasks of the compact programme. These skills included: (a) comprehension skills; (b) recognising given item of apparatus; (c) following instructions; (d) carrying out tasks and handling science apparatus; (e) observation skills; (f) interpretation of the observations; (g) making predictions; and (h) reporting and communicating scientific information.

The tasks were identified to include science process skills. Each activity of the programme encouraged or measured certain skills. The skills most relevant to the compact programme were *observation skills* followed by *using models and theories* and *communicating science information*. The compact programme also included and

encouraged additional skills that were not mentioned in other classification schemes and frameworks such as expressing scientific notations accurately, accurately interpreting written information instructional procedures, etc.

Reliability of practical tests is a well-known problem when attempting to establish consistency in practical task responses. However, the compact programme was found to be satisfactory in terms of meeting the criteria for test item construction advocated by Ebel and Marshall and Hales.

The compact programme also had its strengths and its weaknesses assessed in the context of the Western Cape Education Department Assessment Workbook Criteria, but no indication of irrelevance of the compact programme to these criteria was noted. This field still needs more detailed research.

The compact programme satisfied the basic curriculum criteria advocated by the 2001 Revised National Curriculum Statement Draft, e.g. learner-centeredness, activity-based, durable, etc. This study concluded that different types of activities and programmes should be developed for different criteria.

The core of ten practical items involving 17 activities was investigated with 308 secondary level students and 32 tertiary level participants. The achievement scores of these participants were compared in terms of various groupings of the participants such as their English proficiency, geographical area where the schools/institutions are located, gender, familiarity of the participants with the apparatus used in the practical tasks, etc. The analysis of these results revealed that proficiency in English was related to greater achievement scores on the programme, but it was also observed that this was not the only factor related to achievement level performance. The areas where the schools were located also seemed to be associated with achievement scores possibly implying that resource utilisation or other pre-requisites may also be linked to successful science teaching.

## **LIST OF TABLES**

## **Page No**

Table 1.1 Interaction between the design elements of the Revised National Curriculum Statement Draft (Revised National Curriculum Statement Draft 2001:73)	7
Table 1.2 Key elements of assessment (Revised National Curriculum Statement Draft 2001:73)	8
Table 1.3 Learning Outcome 1: The learner is able to develop and use science process skills in a variety of settings. (Revised National Curriculum Statement Draft 2001:99-100) (abridged)	8
Table 1.4 Learning Outcome 2: The learner is able to develop and apply scientific knowledge and understanding (Revised National Curriculum Statement Draft 2001:37)	9
Table 2.1 The traditional and alternative assessment paradigms	67
Table 2.2 Five subsystems of thinking after Frans (1992: 163)	75
Table 3.1 The Revised National Curriculum Statement Draft (2001) process skills tested by the compact programme of selected core apparatus-based practical items in basic physical science	86
Table 3.2 The consensus views of six experienced teachers of school science on how well the compact programme, as a whole, meets the criteria advocated by the 2001 Revised National Curriculum Statement Draft	88
Table 4.1 Parameters and statistical properties of the final ten core items (consisting of 17 individual tasks), comprising the compact programme of apparatus-based practical activities in basic physical science for a combined sample of n=340 test participants in phase 2 of the investigation	111
Table 4.2 Theoretical effect of deleting single practical task items on the Cronbach alpha coefficient for the whole compact programme ( $\alpha=0.58$ , whole test)	112
Table 4.3 Item analysis: indices of difficulty and discrimination	113
Table 4.4 A comparison of the total achievement test scores of the secondary level group and the tertiary level group	117
Table 4.5 Comparisons of scores of secondary and tertiary level participants on individual items	118
Table 4.6 A comparison of the total test achievement scores of the females and males	118
Table 4.7 Comparisons of the achievement scores of males and females on	119



## individual items

Table 4.8 Comparisons between the total test achievement scores (out of 25) of participant groups at different grade levels	120
Table 4.9 Summary statistics for the performance on each of items 1 to 10 by the secondary level population of 308 participants	121
Table 4.10 Total performance scores of the 308 participants on six unspecified items and on eleven specified items, with reference to the matriculation syllabus	122
Table 4.11 The total achievement test scores of participants classified according to their English language proficiency	123
Table 4.12 Comparison of scores of English first language ( $n_1$ ) and English second language speaking participants ( $n_2$ ) on each item individually	125
Table 4.13 Comparison of total achievements of different schools	126
Table 4.14 Comparisons of schools/institutions on item 3 (magnet pole)	127
Table 4.15 Biserial correlations between total achievement scores and the participants' familiarity with the apparatus ( $N=340$ )	128
Table 4.16 Correlations between participants' achievement scores and the extent of their familiarity with the apparatus in individual test item	129
Table 4.17 Summary of the mean performance scores of the participating groups on the whole test	130
Table 4.18 Affective response words written by participants in the programme to describe the tasks and activities and their frequencies	132
Table 4.19 Process skill words and terms spontaneously used by 340 participants in the programme to describe their activities with the items and apparatus (including tape-recorded words and phrases)	135
Table 4.20 How relevant are the various aspects of Gardner's theory of multiple intelligence to the compact programme of practical activities? The consensus views of eight science/technology educators on a scale of 0 to 3	141
Table 4.21 How relevant are the various aspects of Franus' subsystems of thinking to the compact programme of practical activities? The consensus views of eight science/technology educators on a scale of 0 to 3	141
Table 4.22 How relevant are the various aspects of White's components of memory to the compact programme of practical activities? The consensus views of eight science/technology educators on a scale of 0 to 3	141

Table 4.23 How relevant are the various aspects of Lock's assessment framework for practical skills to the compact programme of practical activities? The consensus views of eight science/technology educators on a scale of 0 to 3	142
Table 4.24 How relevant are the various aspects of Solomon's multiple dimensions of the public understanding of science to the compact programme of practical activities? The consensus views of eight science/technology educators on a scale of 0 to 3	142
Table 4.25 How relevant are the various criteria of practical tasks used by Kapenda et al. to the compact programme of practical activities? The consensus views of eight science/technology educators on a scale of 0 to 3	143
Table 4.26 How relevant are the practical activities to learning outcomes suggested by OBE? The consensus views of eight science/technology educators on a scale of 0 to 3	144
Table 4.27 Analysis of the degree of relevance of the theories to the compact programme of practical activities, as assessed by ten science/technology educators	144
Table 5.1 Question 1.15 appeared in 1999 Standard Grade Physical Science Matriculation Examination paper in the Gauteng Province	164
Table 5.2 Question 9 appeared in 1999 Standard Grade Physical Science Matriculation Examination paper in the Gauteng Province	165
Table 5.3 Questions appeared in 1999 Free State Higher Grade Physical Science Matriculation Examination paper 1	165

## **LIST OF FIGURES**

	<b><u>Page No.</u></b>
Figure 3.1 A measuring cylinder and a solid object	90
Figure 3.2 A formal shoe, a sneaker and a soccer boot	90
Figure 3.3 A compass and three magnets with different shapes	90
Figure 3.4 Two light globes: 100 watt and 60 watt	91
Figure 3.5 A tiny light globe and an objective eyepiece to use while reading the information on the light globe	91
Figure 3.6 Four different arrangements of cells (+ to -, - to -, + to + and two cells in parallel) and a light bulb with two wires	91
Figure 3.7 A circuit involving two resistors in parallel and a third one in series with them; they are altogether connected to two cells	92
Figure 3.8 A circuit that involves two cells in series with two bulbs and an ammeter connected to the circuit at point A	92
Figure 3.9 A plane, a concave and a convex mirror	92
Figure 3.10 A double concave and a double convex lens	93
Figure 3.11 Answer sheet	95
Figure 3.12 The comment sheet	97
Figure 4.1 Distribution of the total scores on the compact programme of 17 practical activities by a sample of n= 340 participants	112
Figure 4.2 Scores of tertiary and secondary level participants	117
Figure 4.3 Total achievement scores of participants classified according to their English language proficiency	123
Figure 4.4 Total achievement scores of participants according to their English proficiency levels and geographical locations	124
Illustration 3.1 The nature of the 442 participants in the research study (phase 1 and phase 2), grouped according to educational status	84

## **LIST OF APPENDICES**

- Appendix 1. Photocopies of published papers and articles in various journals and conference proceedings
- Appendix 2. Samples of the initially developed 33 practical task items' photographs and wordings
- Appendix 3. Samples of the audio-captured conversations of the participants
- Appendix 4. Participants' (high school learners') hand written comments
- Appendix 5. Examples of the re-wording of some of the items that were done during pilot studies
- Appendix 6. Copies of coloured classification cards that were used by the educators and academics to classify the items
- Appendix 7. Further comments on individual items and on the programme in general by the educators and the academics

## LIST OF ABBREVIATIONS

<i>A</i>	: Surface area
AAAS	: The American Association for the Advancement of Science
APU	: Assessment Performance Unit
df	: degrees of freedom
ESL	: English Second Language
<i>F</i>	: Force
GCSE	: General Certificate of Secondary Education
HG	: Higher Grade
<i>I</i>	: Electric current
IGCSE	: International General Certificate of Secondary Education
IMSTUS	: Institute for Mathematics and Science Teaching, University of Stellenbosch
LO	: Learning Outcome
M	: Mean
NCS	: National Curriculum Statement
NS	: Natural Sciences
OBE	: Outcomes-Based Education
<i>P</i>	: Power
<i>P</i>	: Pressure
PEE	: Predict Explore and Explain
QUILL	: The Quality University Industry Linked Learning
<i>R</i>	: Resistance
SAARDHE	: Southern African Association for Research and Development in Higher Education
SAARMSTE	: Southern African Association for Research in Mathematics, Science and Technology Education
SAQA	: South African Qualifications Authority
SCIIS	: Scottish Curriculum Inquiry Integrated Science
SD	: Standard Deviation

SFAA	: Science for All Americans
SG	: Standard Grade
STL	: Science Technology Literacy
TAPS	: Techniques for Assessment of Practical Skills
TIMSS	: Third International Mathematics and Science Survey
TIMSS-R	: Third International Mathematics and Science Survey - Repeat
$V$	: Voltage
WCED	: Western Cape Education Department

University of Cape Town

## CHAPTER 1

### INTRODUCTION

This chapter describes the context, purpose, origin, background and importance of the investigation. It introduces the statement of the research problem, conceptual framework, questions to be answered, clarification of terms, the research approach, list of dependent and independent variables, assumptions of the study, the delineation of the research and organization of the dissertation. The research reported in this investigation has been refereed and disseminated recently by the writer in seven publications, including the refereed *International Global Journal of Engineering Education*, (2001:327-334). A list of these published articles and papers and complete photocopies of these publications are attached in Appendix 1.

#### 1.1 Background and context of the study

Outcomes-based Education (OBE), which is currently being implemented in South African schools, is about systemic change and not only curriculum change.

The White Paper on Education and Training (1995:15) stated that citizens with a strong foundation of general education, with the desire and ability to continue to learn, to adapt and develop new knowledge, skills and technologies, to move flexibly between occupations, to take responsibility for personal performance, to set and achieve high standards and to work co-operatively are the education and training requirement of a successful economy and society (cited in the South African Qualifications Authority (SAQA) position paper 1995:3).

SAQA identified seven cross-field critical outcomes for quality assurance. One of these critical outcomes, re-emphasized in the updated, current Revised

National Curriculum Statement for Grade R-9 Draft: Introducing the National Curriculum Statement (2001:10), states that learners be enabled to “use science and technology effectively and critically, showing responsibility towards the environment and the health of others”.

In Chapter 5 of the White Paper on Education and Training (1995) it is emphasized that an appropriate mathematics, science and technology education is needed, and in the Revised National Curriculum Statement Draft (2001:14) this purpose is again accorded prime purpose.

One of the major emphases of Outcomes-based Education is to teach students how to relate their theoretical knowledge to real life practical situations in the community (Revised National Curriculum Statement Draft, 2001:14-15).

In the new science textbooks that employ an *outcomes-based* approach, the relevant topics are explained through various *activities* in which students need *process skills* to use different apparatus, (e.g. Ayerst, Clarke and Khumalo, 1999). Therefore, in an OBE approach, learners are expected to be able to use, handle and make measurements with different items of simple apparatus and technology.

Many educational problems need to be reconsidered, modified and renewed in the new and developing South Africa, and solutions must be produced for the challenges of the new era where science and technology are in a rapid change. Therefore teacher training and school science require corresponding changes and new approaches to practical work.

Kahn (2000:19) stated that science and technology education plays a crucial role in the development of a country, and that it can be considered as a measure of its development. Specially trained teachers with workable modern teaching



methods must be incorporated into the schools to improve science and technology education.

## **1.2 Statement of the problem, purpose and key questions, and conceptual framework**

Outcomes-based education is *developmental* (Revised National Curriculum Statement Draft, 2001:4). Therefore this study uses sampled groups of respondents at different stages of development to find out initially how familiar and skilled they may be when exploring selected items of everyday basic scientific apparatus. Outcomes-based education is also an “activity-based approach .... designed to promote problem-solving” (ibid). Therefore this study also seeks to establish how well the respondents can *perform with understanding* on specified tasks involving everyday practical science process skills. These enquiries involve hands-on equipment with written instructions for each question, instead of engaging the participants in only the less complex equivalent paper-and-pencil type of test. According to Kellaghan and Greaney (1989:9), traditional paper and pencil examinations ignore other scholastic skills and pay little attention to practical skills.

This investigation seeks to gather information that will address two main problems with regard to selected practical performances in high school science topics. The study will proceed in two phases.

Firstly, in phase 1, during eleven field trials conducted within the context of high school physics teaching, seventeen topic-specific critiques and judgments are to be invited and recorded by each one of 340 users concerning the perceived instructional value and pedagogical effectiveness of a compact programme of ten basic apparatus-based practical activities. These hands-on tasks have been devised and selected for learners to explore their process skills in the syllabus topics *light, statics, electricity and magnetism*. These particular

science activities have been selected and assembled from a larger pool of 33 possible items, also field tested in preliminary trials for this study.

The ten selected core items of practical work, and the programme as a whole, are to be assessed summatively for their appropriate pedagogical strengths and weaknesses in design (i.e. for their instructional value and their quality), using the following literature-derived conceptual framework of didactic questions and performance criteria:

- Does each practical item aim to test/encourage one or more of the 13 **process skills** listed in the Revised National Curriculum Statement Draft (2001: 99-100)? If so, which process skills?
- Do the practical items deployed in this study contain **additional** worthwhile process skills that are **not** mentioned in the Revised National Curriculum Statement Draft?
- After repeated phase 1 field trials to improve the presentation of the apparatus, wording, content and process tasks incorporated into each individual practical item, (and also incorporated into the performance programme as a whole in its final form), do the ten items also meet the following standard criteria for test item construction advocated by Ebel (1972: 359-360) and by Marshall and Hales (1971:165)? (a) Relevance, (b) balance, (c) efficiency, (d) objectivity/ freedom from ambiguity/clarity, (e) specificity, (f) difficulty, (g) discrimination, (h) reliability, (i) fairness, (j) speededness, (k) control, (l) directedness, (m) task specification, (n) validity and (o) standard-based.
- Do the practical tasks satisfy the following additional criteria advocated by the Western Cape Education Department Assessment Workbook (May 2001:4) and by the Revised National Curriculum Statement Draft (2001:73)? (a) Transparency, (b) democratic, (c) participatory, (d) based

on pre-determined criteria, (e) variety of methods, (f) learner-paced, (g) flexibly expansive, (h) criterion referenced, (i) support the learning process, (j) diagnostic, (k) enriches the fast learners, (l) focused and (m) addresses the needs of learners.

- During the eleven phase 1 field trials to improve the apparatus, wording, content and process tasks incorporated into each individual practical item, and into the performance programme as a whole in its final form, does the programme of task items also meet the 37 curriculum criteria advocated by the Revised National Curriculum Statement Draft (2001: 4; 7; 10; 14-16), such as:

- (a) Learner-centeredness
- (b) Activity-based
- (c) Promotes learners' effective use of visual, mathematical and language skills to communicate
- (d) Enables the learners to understand that the world is a set of related systems
- (e) Evidence-based
- (f) Enables prediction, verification and repetition
- (g) Encourages science as a social process
- (h) Requires careful observation
- (i) Promotes an understanding of cause and effect
- (j) Is culture-fair;  
and so on?

Secondly, having continuously improved the clarity and feasibility of the practical performance programme through eleven successive field trials - and having established that the final compact version substantially meets all or most of the benchmark qualities and South African pedagogical criteria outlined above - the investigation then proceeds to phase 2.

It uses the individual items, comprising a pruned total of 17 tasks, and also the refined programme as a whole, to measure and compare collectively the performance scores of different groups of participants at different stages of development in a variety of learning contexts. Several independent variables

are selected, such as the gender, prime (home) language and educational level of respondents, and the geographical location of the participating educational institution. Significant differences in achievement performance scores are then discussed in terms of diversities in the backgrounds and histories of the different types of groups, and in terms of the nature of the recorded comments and responses of participants. When no significant differences occur between mean achievement performance scores, these similarities are also discussed.

Thirdly, the study categorises, analyses and reports the qualitative findings on the overall positive reactions of eleven different participant samples to the practical programme as a whole. It also includes occasional minor reservations or doubts mentioned by one or two students about some aspects of the experimental programme.

Fourthly, using juries of four to eleven expert science educators, the investigation establishes whether there is a perceived relevant **match** or a perceived “irrelevant” **mismatch** between the science process skills tested by the current experimental programme of practical items and the descriptive **theories** of practical science and its classification schemes and criteria proposed by (a) Franus (1992), (b) Gardner (1983), (c) White (1988), (d) Solomon (1998), (e) Lock (1990), (f) Kapenda, Kandjeo-Marenga, Gaoseb, Kasanda and Lubben’s (2001) Cambridge-based International General Certificate of Education after Millar, le Marechal and Tiberghiea (1999), (g) Race (1997) and (h) OBE (Revised National Curriculum Statement Draft, 2001).

If perceived mismatches do occur, perhaps the theories advocated by one or more of these authors ultimately might be rejected as inadequate, faulty, incomplete or irrelevant. Alternatively, mismatches may also occur due to defects in the design of the practical attainment items themselves. If so, should these items be revised yet again?

Finally, the investigation will conclude by proposing a number of substantiated recommendations for teaching selected aspects of high school physics practical work, based on the evidence systematically presented and analysed in this study.

### 1.3 Origin and purpose of the problem

Table 1.1 presents the 13 current science process skills (abridged) proposed in the Revised National Curriculum Statement Draft: Natural Sciences Learning Area: Senior Phase (2001:52, 99-100) for the attainment of national **Learning Outcome 1**.

Table 1.1 Learning Outcome 1: The learner is able to develop and use science process skills in a variety of settings. (Revised National Curriculum Statement Draft 2001:99-100) (abridged).

Learners will gradually develop process skills needed for scientific inquiry. Learners should access information:

- In traditional ways
- In practical ways

#### **Process skills**

The meaning of the various process skills used in the document are as follows:

- Observing and comparing
- Measuring and estimating
- Recording information
- Sorting and classifying
- Interpreting information
- Predicting what will happen if something changes
- Hypothesising
- Using models and theories
- Raising questions about a situation
- Planning investigations
- Doing the investigation
- Communicating science information
- Design, make and improve a device or system to solve a particular problem

Hence, applying Table 1.1, this investigation will derive and evaluate a compact programme of practical items in high school science, drawn from the textbook

content on *optics, statics, electricity, magnetism*, etc., with the goal of exploring the attainment of as many of these 13 prescribed *process skills* as possible by participant learners, working as individuals but free to discuss the practical activities with each other democratically before making a final response during phase 1 of the research. This will occur in a limited period of classroom time, through activity-based, learner-centered, problem-solving involvement formulated according to the national curriculum design and assessment elements recorded in Tables 1.2 and 1.3.

Table 1.2 Interaction between the design elements of the Revised National Curriculum Statement Draft (Revised National Curriculum Statement Draft 2001:73)

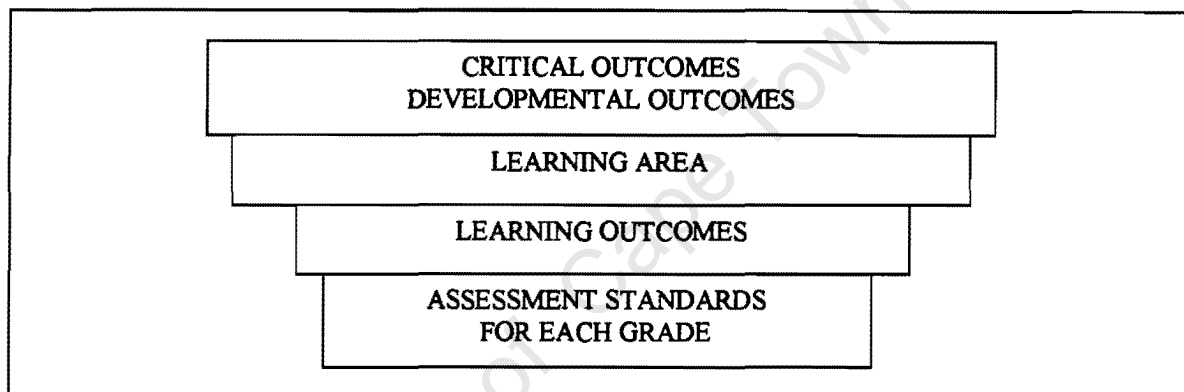


Table 1.3 Key elements of assessment (Revised National Curriculum Statement Draft 2001:73)

To help learners to reach their full potential successfully, assessment should be:

- Transparent, democratic, clearly focused and participatory.
- Integrated with teaching and learning.
- Based on pre-determined criteria or standards.
- Integrated, in making use of integrated tasks and activities, and a variety of methods, tools, techniques and contexts in assessing learners' performance.
- Valid, reliable, fair, learner-paced, and flexible enough to allow for expanded opportunities.

During the course of attaining these process skills, it is expected that learners, in part, "will thus be expected to apply the major principles, laws and concepts of science to explain the nature of the world and to make verifiable

predictions". This is national **Learning Outcome 2**, as reproduced in Table 1.4. Hence, this investigation intends to present evidence documenting the extent to which the programme of practical items is effective in facilitating the attainment of national Learning Outcome 2 with a wide diversity of respondent samples with different educational backgrounds.

Table 1.4 Learning Outcome 2: The learner is able to develop and apply scientific knowledge and understanding (Revised National Curriculum Statement Draft 2001:37)

There has been an explosion of scientific knowledge in recent times as societies have realised the importance of science in economic, social and political advancement. Technology has also played its part in providing more advanced tools for research and for accessing information. It is now impossible for an individual to keep pace with the knowledge explosion.

The idea is that the learner will deal with the major generalisations and achievements of science, without going into fine detail and without acquiring a vast amount of factual information.

Learners will thus be expected to apply the major principles, laws and concepts of science to explain the nature of the world and to make variable predictions.

Many investigations have been conducted in Britain, the United States, South Africa, etc. during the last few decades to investigate the levels of scientific literacy and the conceptual difficulties of science learners and teachers, e.g. Galili and Bar (1992), Twigger, Byard, Driver, Draper, Hartley, Hennessy, Mohamed, O'Malley, O'Shea and Scanlon (1994), Gilbert, Watts and Osborne (1982), Zhaoyao (1993), Laugksch and Spargo (1996), Palmer (1997), Trumper (1996), and Howie (1997). However, in most of these studies the adopted assessment research instruments consisted of paper-and-pencil type tests only, which is not necessarily what active science is all about, as will be explained below.

Therefore, this innovative research study explores the feasibility and efficacy of a systematic *practical task-based* approach to diagnostic assessment in everyday scientific situations. Instead of using a paper-and-pencil type of evaluation, a hands-on exploratory programme which comprises a sample of 17 formulated assessment tasks and items (selected out of an experimental pool of

33 trialled items) is to be used to gather detailed response data from different groups of voluntary attendants.

A recent Western Cape Education Department syllabus document for Physical Science (1996:1-2) stated, *inter alia*, the following aims and policies:

- 1.1.2. To develop in learners the necessary skills, techniques and methods of science, such as handling of certain apparatus, the techniques of measuring and observation and information retrieval.
- 1.1.6. To introduce learners to the applications of science in everyday life and in industry.
- 1.3.3. The practical work forms an integral part of the syllabus and plays an important role in understanding scientific principles and phenomena. It must therefore be regarded as an essential aspect of science teaching.

The development of a society requires scientifically and technologically literate people. Recently the Senior Phase policy document of the South African Department of Education (1997:Tech 3) required learners to demonstrate an understanding of the *application* of the technological process to solve problems and satisfy needs and wants. It also emphasised the importance of understanding the impact of technology on people's social life, on the economy and on the development of society. Hence, it is in this wider context that the present investigation is located.

#### **1.4 Importance, significance and value of the study**

According to the results of the Third International Mathematics and Science Study-Repeat, TIMSS-R, (Howie, 2001), in general, conditions for learning science and mathematics in South Africa were not favorable compared to other countries which participated in this study. The majority of the teachers whose students participated in this study did not feel confident about their preparation as science and mathematics teachers.



The Revised National Curriculum Statement Draft (2001:1) has identified three main purposes of the Natural Sciences Learning Area. According to this document, the revised Learning Area serves to ensure that all learners:-

- 1- become scientifically literate by the end of grade 9;
- 2- acquire certain scientific skills, attitudes and values that they will use in all walks of life; and
- 3- understand the full implications of scientific activity on humanity.

In the same document the Natural Sciences Learning Area is organized around three strands: *learning science*, *doing science* and *science and society* (p 2).

The advantages of scientific literacy have been identified as follows in the draft document:

- It ensures the existence of well-informed citizens who are capable of making judgments and decisions based on logic and reason.
- It lays the foundation for further studies in Natural Science for those who elect to do so. This increases the fund of information and skills available to us: information and skills that may have enormous potential in leading to solutions to local, national and perhaps global problems.
- It provides opportunities for a variety of pathways, leading to economic empowerment.

The Revised National Curriculum Statement Draft document (2001:1) states that the teaching and learning of science by working in ways that scientists do (“doing science”) helps learners acquire these skills described above. The “doing science” strand in the Natural Sciences Learning Area provides learners with opportunities to work in ways similar to scientists. In addition to the ways of assessing the acquisition of information in traditional ways - such as tests, journals and other reliable sources of information - learners should be given the opportunities to use more innovative ways of assessing information such as talking to experts, designing and carrying out investigations, etc. Doing science

in these ways not only helps to develop the above mentioned process skills but also enhances the learning of scientific principles, laws and concepts (Revised National Curriculum Statement Draft 21, 2001:3).

One of the major changes brought by the new Revised National Curriculum Statement Draft is that the nine specific outcomes of learning Natural Sciences have been reduced to three, and each one of these outcomes matches one of the strands mentioned earlier. These learning outcomes are presented in more detail in Chapter 2. The document states that a systematic method of study requires certain skills, attributes and values; and that teaching and learning the ways of scientists (by doing science) help learners acquire these skills.

Khoali, Bapoo and Rollnick (2001) reported a study that was aimed at establishing the validity of an existing questionnaire used as an instrument to probe high school students' experience with chemistry practicals. They conducted the questionnaire among 98 Grade 12 students from four schools in the Johannesburg area. With this instrument they could also identify *everyday familiarity*, *book familiarity* and *familiarity with a laboratory*. They also interviewed 16 students to check their response consistency with the responses they gave to the questionnaires.

They reported that, in general, the students from the four schools showed *book familiarity*; however, good *lab-familiarity* was absent. Good *lab-familiarity* meant the students were actively involved with the laboratory activities individually rather than with just group work or teacher demonstration. Some of their findings were:

- 1- Naming of common laboratory apparatus was difficult.
- 2- Some students had difficulty in naming and giving the uses of laboratory apparatus.
- 3- Students reported that they either performed a few activities or were not exposed to practical work.

- 4- Students simply associated the use of certain apparatus with a particular activity in which they were engaged.

The authors recommended that, instead of using the diagrammatic representations of apparatus, it would be ideal for South African school students to use real apparatus in their investigations; hence the importance of the current research study now being presented.

Isaacs (2001) examined the three learning outcomes of the Natural Sciences offered by OBE that form the basis of the assessment of learners:

1. The ability to demonstrate an understanding of scientific principles, laws and concepts.
2. The ability to carry out scientific activities and to apply scientific principles, laws and concepts.
3. The ability to demonstrate an understanding of the relationship between science and society, and the impact of science on society.

He argued that learning about science does not bring about a complete understanding of scientific principles, laws and concepts. Therefore learners must be given opportunities to work in ways scientists do. Doing science not only develops the necessary skills but also enhances the learning of scientific principles, laws and concepts.

In the USA, Guzzetti, Williams, Skeels and Ming Wu (1997) studied the influence of text structures on the conceptual change of university physics students. One of their findings was that 55% of Physics students and 48% of Honours students reported that they learned concepts best from *experiments, laboratories and hands-on activities*. By contrast 37% of Physical World students stated that they learned best by studying their notes and repetition and memorizing.

Howie (2001) concluded from the results of TIMSS-R that the challenges for education in South Africa are continuing to mount; and that much has to be

done in the coming years to improve the quality of South African education - in particular science and mathematics education. She also stated that, if South Africa wants to succeed in a rapidly changing and competitive technological world, there is an urgent need to increase the number of pupils with the adequate and well-founded knowledge and skills in science and mathematics to create a critical mass of matriculants who are able to move into higher education, business and industry in the short, medium and long term.

### **1.5 The nature of the problem: issues of assessment**

Kapenda et al. (2001) examined the practical work conducted in Namibian schools with regard to the aspects of task design (inductive-deductive, open-closed and nature of student involvement) and context of practical work (duration, interaction patterns, types of task information and apparatus and nature of the student record). They stated that, after Namibia became independent in 1990, it underwent a reform in its education system; namely, the Cape curriculum was replaced by a Cambridge-based International General Certificate of Secondary Education (IGCSE). Practical work however, was absent from most of the school subjects. The IGCSE curriculum for each science subject is basically divided into three assessment domains: Domain A- knowledge with understanding; Domain B- handling information and solving problems; and Domain C- experimental skills and investigation (p 413).

They used the Profile Form developed by Millar et al. (1999) which included eleven possible learning outcomes of practical work. They reported that about half of the observed practical work aimed to familiarize students with objects or phenomena, and support the students in learning a scientific relationship. In terms of procedural outcomes, two thirds of the practicals were aimed at helping students to use data to support conclusions, and half of the practicals intended to provide practice of a standard procedure. No lesson was observed where it was intended to communicate the results of the experiment.

There was a differentiation between object-driven and idea-driven tasks in the Profile Form used in this research. However IGCSE Biology and Physical Science syllabi did not clearly identify what learners were intended to do with the objects and ideas, i.e. whether tasks should be object-driven or ideas-driven (p 415). Kapenda et al. (2001:415) also observed that, in general, the practical tasks were closed in nature. The teacher prescribed the question to be answered and the method of the practical, and even the data handling method was described in some cases.

Visser (2000) presented a workshop at a Science and Technology Education Conference which focused on issues around the problem of teaching practical work in physical science in secondary schools in South Africa. In this workshop were discussed the necessity of practical work, strategies of conducting practical work, implementation of these strategies and the assessment of practical work. Visser suggested three strategies for conducting practical work and their assessment which were: stations involving a number of different experiments; predict, explore and explain (PEE) where a well-chosen question is discussed among students; and strategies with the teachers' and students' own design and execution.

The complete process of science cannot be learned by merely reading, listening, memorizing or problem solving but effective teaching requires active mental involvement (Visser 2000:184). All sciences are built with information from direct experiments and the nature of the subject rests heavily on the interaction between the theory and the experiment. For conceptualization to occur, learners must be both mentally and actively involved.

There have been several issues around the nature of the practice of assessment strategies in science. Champagne and Newell (1992:841) argued that

assessment is a highly political process and a critical issue in today's education world.

Race (1997:18) argued that many areas of study involve practical work, but it is often much more difficult to assess such work in its own right. Assessing reports of practical work may involve measuring the quality of the end-product of the practical work but not the work itself. He laid out some suggestions for assessing practical work:-

- Reserve some marks for the process.
- Get students to self-assess how well they undertook tasks.
- Ask students to include in their reports "ways I could do the experiment better next time".
- Include some 'supplementary questions'.
- Design the right end-products.

Race (1997:37) pointed to the danger of measuring the final product of certain skills and ignoring measurement of the skills themselves. He laid out ten questions and suggested that addressing these questions may help to get the balance right. These questions consisted of the following:

- 1- What exactly are the practical skills we wish to assess?
- 2- Why do we need to measure practical skills?
- 3- Where is the best place to measure these skills?
- 4- When is the best time to measure these skills?
- 5- Who is in the best position to measure practical skills?
- 6- Is it necessary to establish minimum acceptable standards?
- 7- How much should practical skills count for?
- 8- May student self-assessment of practical skills be worth using?
- 9- May student peer-assessment of practical skills be worth using?
- 10- Is it necessary to have a practical examination?

Thus, these are the types of issues and suggestions which will be addressed in the current investigation in the light of evidence which will be gathered both systematically and opportunistically.

Wilkinson and Ward (1997) suggested that laboratory work should be assessed and should form part of a student's overall assessment.

Lock (1989) introduced an assessment framework for practical work skills appropriate to students of secondary school age (11-18 years). He studied the relationship between the component skills of practical work such as observation, manipulation, interpretation, planning, report and self-reliance. He concluded that the skills of interpretation and planning are strongly related to each other.

Buchan (1993:7) noted that there had been major changes in British science education policy, and stated that commitment to practical work was central to these changes. However the role of practical work had not been defined. The debates were focused on how to assess students' practical competence, not on the purpose behind developing this competence. She argued that there is no set role for practical work universally.

Introduction of the assessment schemes in the United Kingdom provided a framework for practical science which teachers used to analyze practical experiences they provided for pupils. One perceived advantage of the introduction of practical assessment was improved motivation on the pupils' side, but this was not accepted universally (Buchan 1993:13).

## **1.6 Clarification of terms**

**1.6.1. Physics:** refers to the study of energy and matter and their relationships.

- 1.6.2. **Scientific literacy** (the public understanding of science): 1- The ability to read, write and understand systematised human knowledge (Branscomb 1981, cited in Laugksch 1999:5); and 2- the ability to place news of the day about science in a meaningful context (Hazan and Trefil 1990, cited in Laugksch 1999:8).
- 1.6.3. **Practical (manipulative) scientific literacy**: refers to possession of the kind of scientific knowledge and skills that can be used to help solve practical problems (Shen 1975a, cited in Laugksch 1999:5).
- 1.6.4. **Paper-and-pencil type tests**: refer to tests that do not involve any actual apparatus or practical task manipulation.
- 1.6.5. **Practical test items**: refer to 33 test items or tasks (ten subsequently selected) that involve pieces of actual apparatus to be manipulated, as well as to the instructions requiring the demonstration of performance skills by an active participant, in this particular study.
- 1.6.6. **Science process skills**: refer to any ability that helps a person do science such as observing, inferring, classifying, questioning, predicting, experimenting, data analyzing and communicating (Rillero, 1998:3). The skills investigated in this study have been defined and identified in Table 1.1 on page 7.

## 1.7 Delineation of the research

The study is restricted to

- Participants in the age range 12 - 30 years in phase 2.
- Specifically chosen topics in physics rather than in all school science disciplines.
- A programme of ten core items selected for four basic topics.
- Conveniently available groups in the Western Cape Province.



- A limited time period, usually 25-30 minutes for each student to complete the compact programme of ten practical tasks.

### **1.8 Assumptions of the study**

The study assumes that the respondents are of good eyesight, perceiving structures, apparatus and instructions with reasonable accuracy. It also assumes that the participants are interested in practical applications of the theory which they have learned about in school and/or encountered in everyday life. It is assumed that each student can maintain concentration on the programme for 30 minutes. The study also assumes that the participants are interested in practical items, even if their prior knowledge is minimal.

### **1.9 Research approach**

The research approach adopted is a combination of qualitative and quantitative methodology. Chapter 3 elucidates the issues around the selection, development, validation, purification, evaluation, pruning and classification of the activities according to item analysis, different learning theories and frameworks, and outcomes of learning science. The relevance of these theories and frameworks will be explained in Chapter 2. The quantitative approach employs the use of indices of difficulty and discrimination and correlations, chi-square and t-tests in Chapter 4 to compare the response frequencies and scores of different sample groups on individual items and on the test as a whole. In Chapter 4, the qualitative approach also involves an analysis of the recorded observations of the respondents during both phase 1 and phase 2 of the study. It involves interviews and categorical classifications of the observed and written descriptive responses of the participants, using clusters of common indicators and sets of emergent themes, used for improving and describing the practical programme as a whole.

For the purpose of this research the responses have been collected by means of interviews, observation and answer sheets which have been developed through several pilot trials, and tape-recorded conversations of participants during the developmental stages.

### **1.10 List of dependent and independent variables**

The following variables have been selected for both qualitative and quantitative investigation in this study: -

#### **1.10.1. Dependent variables for each participant**

- Summative practical performance achievement scores of each student (assessed out of a possible total of 25 marks).
- Degree of familiarity of the students with each individual piece of the apparatus used in the test items (designated on a scale of 0 to 2).

#### **1.10.2. Independent variables for each participant**

- Gender (male or female)
- Primary language (English, Afrikaans, Xhosa, and others)
- Grade level (Intermediate phase, Senior phase, tertiary level etc.)
- Schools/institutions in which the participants are based.

### **1.11 Hypotheses**

The variables: gender, respondents' home language, degree of familiarity with each item of apparatus and grade level are used to formulate 14 null hypotheses in relation to comparisons of groups' mean practical achievement performance

scores. The performance scores of the secondary level participants will also be analysed according to the items' inclusion in the matriculation syllabus. These hypotheses are presented in full detail in Chapter 3.

### **1.12 Chapter summary**

In this introductory chapter the purposes of the research have been presented, the research problem has been clarified, and its origin, context, importance and background stated. The aims of the research, key terms, assumptions and variables have been clarified. The research approach and its delineation have been mentioned.

In the next chapter the relevant literature will be reviewed and the theoretical framework and the categories for classification for the selected practical activities will be provided.

### **1.13 Organization of the remainder of the dissertation**

The next five chapters are arranged as follows-

Chapter 2 introduces the relevant literature review; Chapter 3 explains in detail the methodology of the research and the development, refinement and statistical parameters of the final version of the compact programme of practical activities; Chapter 4 tests the hypotheses and presents the results of the study; Chapter 5 discusses the quantitative and qualitative results; and finally Chapter 6 draws conclusions and implications and makes recommendations based on the findings and the discussion of these results.

## CHAPTER 2

### LITERATURE REVIEW

This chapter is presented in 13 sections.

Following the recent release of the Revised National Curriculum Statement Draft's (2001:99-100) emphasis on science process skills, section 2.1 reviews the importance, purpose, strategies, nature, hierarchy, generalisability, assessment and investigative nature of school science process skills, with special reference to Harlen (1999), the TAPS project (Bryce 1991) and Lock (1989).

Section 2.2 examines the interrelationship between science process skills and the aims of practical work.

Section 2.3 introduces the theory of White (1988) and suggests that his ideas on strings, propositions, images, episodes, skills and strategies might be useful for a theoretical analysis of basic science process skills.

Section 2.4 explores the notions of scientific literacy and technological literacy in the context of the work of Hurd (1998), Solomon (1998), Miller (1983), Jenkins (1994), Shen (1975a; 1975b), Laugksch (1999; 2000) and Laugksch and Spargo (1996).

Section 2.5 focuses on recent studies in scientific literacy and achievement such as the TIMMS conducted in 1997 and repeated as TIMMS-R in 1999 (Howie, 2001).

TIMSS TIMSS

Section 2.6 reviews research findings on the teaching of specific content areas of science relevant to the present study, such as electricity, mechanics and optics.

Section 2.7 reviews methods of teaching everyday science.

Section 2.8 discusses the role of continuous assessment, and assessment in general, in science classes.

Section 2.9 introduces teacher training issues in science practical work.

Section 2.10 summarizes recent gender issues in science learning and achievement.

Finally, sections 2.11 and 2.12 introduce the theories of Franus (1992) and Gardner (1983), and suggest how scientific thought systems and processes might fit into their schemes of learning.

### **2.1. Science process skills**

Learners face academic science in primary and secondary school for the first time, and this makes the teaching of science and technology in schools important, because it is important for the learners to get a positive impression at their first experience with academic science. A positive impression may help learners to have a positive attitude towards school science and also learners may be encouraged to continue science at their later school career. Some basic concepts and ideas must be taught in primary and secondary schools, especially in an era of rapidly changing technology. Therefore a new approach to primary and secondary curricula is needed. Having pointed out these issues, Pudlowski (1990) introduced new programme structures and selected core courses in several curricula for engineering teachers, with a particular emphasis on hands-on experiences.

Harlen (1999:130) has discussed the assessment of process skills for three purposes: formative, summative, and national and international monitoring. He stated that learning with understanding involves linking new experiences to previous ones. In this way ideas developed in relation to specific phenomena become linked together and they become 'big ideas' to have more explanatory power. The development of the science process skills is crucial in this process: if these skills are not developed well, contrary evidence emerging from new experiences may be ignored and preconceptions will prevail. This will not help understanding of the world. ✓

Harlen (1999:130) argued that science process skills are important not only in terms of preparing future scientists but also for the whole population who need scientific literacy in order to live and function in a world where science impinges on most aspects of personal, social and global life. Therefore science process skills need also to be assessed as well as understanding of science concepts as end products. He also pointed out that it is important to assess process skills only when conceptual understanding is not an obstacle to using these skills. If learners are experiencing problems in comprehending the scientific concepts (content) they may not be expected to use process skills to apply their understanding of these concepts. \*

Harlen (1999:132) suggested four strategies to gather information on the development of science process skills to utilise for formative purposes:

a) observing pupils; b) questioning, using open questions phrased to invite learners to explore their ideas and reasoning; c) setting tasks in a way which requires pupils to use certain skills; and d) asking pupils to communicate their thinking through various ways such as drawings, actions, role play, concept mapping etc. *assessment*

To identify a focus for further learning, teachers should have an understanding of the development of these skills. Harlen (1999:133) suggested the technique

that was outlined by Harlen and Jelly (1997) who proposed a list of questions for each component skill concerned such as observing, explaining, predicting, raising questions, planning, communicating etc. These lists of questions can be used by the teachers as checklists to monitor the development of pupils.

✓ Harlen (1999:133) stated that assessment is formative only when it is used to help learning. He suggested six strategies that teachers can use:

- 1- Provide an opportunity for using process skills;
- 2- Encourage critical review by students of how their activities were carried out and how they could be improved;
- 3- Give feedback in a form that focuses on the quality of the work not on the person;
- 4- Give students access to examples of work which meet the criteria of quality and to point out significant aspects of the work;
- 5- Engage in metacognitive discussion about procedure so that students see the relevance of their work to other investigations;
- 6- Teach the techniques and the language needed as skills advance. ✓

Harlen (1999:136) pointed out that five of six categories of the Assessment Performance Unit (APU) in England, Wales and Ireland were related to process skills and three of them involved practical work. He argued that learning does not end with formal education but must continue throughout life requiring the skills of finding, evaluating and interpreting evidence. Therefore he emphasized that the level of achievement of learners in these skills is a measure of their preparation for future life and must be part of summative assessment. He suggested that evidence collected during formative assessment could be used for summative purposes by interpreting them against external standards and criteria that are used for reporting purposes.

Rillero (1998:3) stated that science process skills drive the doing of science, and science content knowledge is the knowing of science. He stated that any ability that helps a person do science is a science process skill such as observing, inferring, classifying, questioning, predicting, experimenting, analyzing data and communicating. He argued that gaining such skills is not

only important for those who pursue a science-related career, but also because it is difficult to imagine a career in this millennium that does not involve science.

Rillero (1998:4) stated that science content knowledge and process skills are important and complementary. He argued that activity-based learning can offer a context for both.

Brotherton and Preece (1995) investigated hierarchies of science process skills and their relation with Piagetian development level. They observed only a two level hierarchy (basic and integrated) of process skills and they found no evidence to support a theoretical multi-level model. They reported finding an overlap between developmental level and process skills. Two-levels of skills hierarchy were in parallel with concrete and formal levels in Piaget's scheme.

Auntoh and Woolnough (1994) discussed and investigated the generalisability of six laboratory based process skills: preliminary trials, planning, performing, communicating, interpreting and feedback. They observed that two of the six skills (preliminary trials and planning) are generalisable, one (interpreting) is context-dependent and three (performing, communicating and feedback) are inconclusive.

Donnelly (1987:135-146) reported findings on variable-handling aspects of pupil performance in investigatory tasks using data from the British Assessment Performance Unit national survey programme which included both practical and pencil and paper type test items. In this study he observed that much lower performance skills were common when the students were asked to state their approach to experimental design. Finally he concluded that, to investigate more fully the pupils' usage of control-of-variables techniques, one would need first to investigate their underlying conceptions of "variable" and of "instrumentality" as a central criterion in the validation of scientific knowledge.



Harlen (1999:139) examined science process skills and their assessment and pointed out that, for formative assessment, the validity of the instrument is more important than its reliability. ✓

Lock (1989) introduced an assessment framework for practical work skills appropriate to students of secondary school age (11-18 years). This assessment framework was validated for him by a panel of ten experienced science educators. He used this assessment framework to study the relationships between the component skills of practical work. The practical skills concerned were:

- Observation
  - Observe accurately (with correspondence between the record and the event, as seen by a supervisor)
  - Read instruments correctly
- Manipulation
  - Set up apparatus appropriately
  - Use apparatus/materials appropriately
  - Work accurately/systematically with hands/fingers
  - Carry out operations in correct sequence/follow instructions
- Interpretation
  - Interpret observations
  - Interpret numerical data/diagrams
  - Indicate sources of errors (in material and in methods)
  - Ability to calculate
  - Make predictions
- Planning
  - Devise a simple experimental procedure (including selection of apparatus, measuring instruments)
  - Use of controls/trial experiments/observations
  - Problem-solving
- Report
  - Use scientific language (written/verbal)
  - Arrange/organise the data/observations
  - Accuracy with which the procedure is reported
- Self-reliance
  - Asking for assistance and for confirmation of approach.

Lock concluded that the skills of interpretation and planning were strongly related to each other.

In the present investigation, this assessment framework will be used by juries of expert science teachers to classify the ten practical test items developed in this study according to their relevance to certain skills identified by Lock. The ways of improving these practical items will also be discussed in the light of this and other theoretical assessment frameworks.

Techniques for the Assessment of Practical Skills (TAPS) was a three phase research study focused on assessing open-ended practical investigations and developed in Scotland for use by science teachers in Scottish schools. TAPS 1 was developed to conduct practical assessment of pupils aged 14-16 years for basic skills and TAPS 2 was used for assessing process skills. TAPS 3 formed the basis of assessment of investigative skills (Bryce, 1991:12).

Bryce (1991:12) set out twelve advantages of using TAPS 3:

- 1- The questions/instructions in the pupil's investigation booklet ensured a focus on the scientific skills required during investigation.
- 2- Pupils were encouraged to investigate their own ideas and develop their own strategies in response to a starter question.
- 3- Pupils based practical work on their own working hypotheses.
- 4- Each starter question generated 3, 4, 5 ... variables/practicable investigations.
- 5- Using group discussion to launch investigations was productive and enabled teachers to assess the prospects for individual investigations.
- 6- Practical investigations provided realistic contexts for the control of variables.
- 7- Particular experimental techniques were perceived by pupils to be useful.
- 8- The procedure cards enabled pupils to carry out effective investigations on themes/variables of their own choice, or they could provide back-up to allow pupils to complete an investigation.

- 9- The assessment criteria were designed to establish standards and contribute to good practice.
- 10- Formal practical assessment dovetailed with the teaching of investigative skills and strategies.
- 11- Completed investigation booklets provided a record suitable for later grading and moderation purposes.
- 12- The management strategy was flexible and allowed whole classes to be assessed in reasonably large groups.

Bryce (1991:17) also mentioned three difficulties with TAPS 3. Firstly, preparation was required by teachers; secondly pupils were not necessarily used to investigative work; finally, these investigations took time.

The implications of this review for the present study are that the evidence gathered from the respondents in Cape Town will be used either to support or to moderate at least some of the above claims of these various theorists' ideas.

## **2.2. The skills and aims of practical work**

Many problems need to be reconsidered, modified and renewed in South Africa and some quick solutions must be encouraged for the challenges of the new era where science and technology are in rapid change. Therefore teacher training and science teaching at schools will also require some important changes and new approaches. According to Kahn (2000), technological development must be based on science, mathematics and technology education. He also underlined the fact that the curriculum should include the scientific and mathematical understanding of technology in everyday life, such as: rehydration, how to attach a three-pin plug to a kettle, jump-starting a car, the nature of air and water pollution, appreciating risk and financial planning, and so on. He emphasized that science and technology education plays a crucial role in the development of a country, and it can be considered as a measure of its

development. Therefore, specially trained teachers with modern teaching methods must be injected into the schools to improve science and technology education.

Hudson (1990:39) argued the value of practical work in science education and stated that all we could say is that some teachers are able to use practical work successfully with some children, and achieve some of their goals.

Hudson (1998) stated that there are many newcomers to the profession who are unsure about how best to design and implement hands-on work in school science. To find a way out of this situation he suggested to reconceptualise practical work in terms of three associated purposes: 1) to help students learn science - i.e. to acquire and develop conceptual and theoretical knowledge; 2) to help students learn about science - i.e. to develop an understanding of the nature and methods of science and an awareness of the complex interactions among science, technology, society and environment; and 3) to enable students to do science - i.e. to engage in and develop expertise in scientific enquiry and problem-solving. Finally he concluded that practical work could be a very powerful way of developing students' conceptions and procedural understanding. It is capable of providing first hand experiences of scientific inquiry and assisting the development of personal expertise in students. Therefore the method of using a practical component of science in teaching is very important and requires appropriate training.

In the present study the practical experience is presented in the form of a hands-on programme that can also be used to diagnose problems encountered by learners and measure their levels of attainment of desired skills and knowledge.

Wilkinson and Ward (1997) surveyed the opinions of science students and their teachers regarding the purpose and the effectiveness of laboratory work. They described laboratory work as being involved in experimental activities and

practical work as a broader term covering excursions, field trips, role-play activities and demonstrations etc. They concluded that a distinction should be made between practical work and laboratory work; only then can we make a valuable analysis and conclusions.

In a study that focused on the context-dependency of pupil practical skills and on the construct validity of practical skills, Lock (1990) compared pupil performance on a range of practical tasks with external examination grades awarded in biology and chemistry. He found that *observation* and *reporting* skills appeared to be context-dependent whereas performance on the *interpretation* and *self-reliance* skills were generalisable. He emphasized that practical work should be given a prominent and discrete place in the assessment of science subjects.

In the late 1980s the National Science Board Commission of the United Kingdom developed new science curricula that incorporated appropriate scientific and technological knowledge and were oriented toward practical issues. The data obtained in the implementation process of Scottish Curriculum Inquiry Integrated Science (SCIIS) showed that the attitudes of students toward science, who were doing science, rather than just reading and language arts in this programme, were greatly enhanced (Kyle, Bonnstetter, Gadsden and Shymansky, 1988). The current study will therefore not ignore the incidental attitudes and reactions of the participants to an exploratory practical assessment test in physics.

Studies focused on the notion of 'life-long learning' have led to a theory of 'situated learning' or 'authentic learning' that presents a clear challenge to conventional curricula and teaching approaches. In countries like the USA and Canada a curriculum reform movement known as 'applied academics' is now emerging which places an increased emphasis on the acquisition of academic concepts and principles through classroom and laboratory activities that connect

abstract knowledge to workplace applications. It is important that emphasis be given to this in South Africa's new National Curriculum.

Mank (2000) argued that it would be possible to acquire much knowledge of scientific information without doing any practical work at all. However, it would not be possible to learn how to work as a problem-solving scientist in such a way. So those who are concerned to teach the *process* of science should realize that practical work is vital. If we are concerned about "life-long learning" of our learners, mere knowledge acquired without any practical experience may not provide the outcomes that we desire.

Clackson and Wright (1992) reviewed the past evaluation and research on practical work to examine the suitability of current practice for learning science in the future. They stated that practical work, almost universally, was regarded as desirable, if not essential. However most of the research appeared to be inappropriate for current schemes and, in many cases, such evidence was unavailable. They reported that there was criticism about the *effectiveness* of practical work. However such criticism was not based on scientific evaluation of individual practical work.

Clackson and Wright (1992) argued that earlier studies all focused on a comparison of the relative effectiveness of individual practical work and teacher demonstration. However there was insufficient evidence about the superiority of either approach. They quoted the findings of Yager, Engen and Snider (1969) on the effectiveness of practical work, which stated that classes taught with laboratory demonstrations and individual practical work develop more skills than the classes with no laboratory experience at all.

Coulter (1966) (cited in Clackson and Wright, 1992) referred to traditional practical work as a 'deductive approach' and they developed an 'inductive approach' in which pupils designed their own experiment to solve a suggested

problem. Clackson and Wright (1992) argued that the inductive approach tended to impart a better appreciation of scientific enquiry. They reported that the use of demonstrations by film or video would be an effective alternative to practical work. Another problem identified with practical work was that the learning process was hampered by too much information presented at once.

Hence, items used in the present study will not involve too much detail, so that the participants will be able to focus on the desired outcome of the assessment item.

Clackson and Wright (1992) argued that practical science could be treated as a subject in its own right. They also suggested that the aim of the practical work should be clear to consider if the current practice was the best approach.

Wilkinson and Ward (1997) compared the opinions of students of different achievement levels, and the opinions of students with their teachers, regarding the aims of practical work. Both students and teachers ranked "to make science more interesting and enjoyable through actual experience" as the most important aim. "To give practice in following a set of instructions" and "to prepare students for examinations" were considered to be of the least importance. Wilkinson and Ward (1997) found that the responses of the male and female students were statistically different, and that their achievement levels also influenced what the students expected from the laboratory work. The reason for the low ranking of "to prepare students for practical examinations" may be the lack of practical examinations. When a formal practical assessment is involved it may be necessary to involve such practice in school science teaching.

They also compared the opinions of students with their own teachers and the results revealed that in five of six schools the students had different views from their teachers. They stated that, in each school they surveyed, both teachers and

students shared the view as: having formal rules to follow, working in small groups, and discussing the results soon after the experiment is completed. They suggested that laboratory work should be assessed and should form part of a student's overall assessment.

Watts and Bentley (1989) reported four case studies. In one of these case studies a teacher stated that he has become increasingly committed to practical work as a means of developing pupils' skills but, more importantly, it was a purposeful way of learning about the world. They quoted that the findings of the Assessment Performance Unit revealed that it was not always successful to use routine (passive) practical work. The children should be given the opportunity to produce their own experiments and test out their ideas.

Watts and Bentley (1989) stated that children's thinking, conclusions, interpretations, and ideas were not the same as what teachers thought they would be. They stated that telling by itself did not always give desired results. For active learning to occur, children should be involved in the learning process. An active learning process requires the students to interpret the events or concepts and to develop their own understanding.

Therefore the kind of practice that is presented in this current research will be utilized in this way. After the learners complete the test the results will be opened for discussions and the desired responses may be given and the learners will be expected to interpret their own response and the correct response.

Kahn and Volmink (1999) argued that the anticipated improvement in inquiry and problem solving skills expected of laboratory activity does not occur without special mediation through discussions, further interpretation and methodical development of conclusions. Therefore the standard organization of practical work is questionable, and meaningful learning should be presented as part of an inquiry that will lead to further questions. For a better discussion it is



necessary to get the learners involved in the *interpretation* of the items. After the learner gives a response then it can be discussed for better outcomes.

Closed, content-dominated practicals leading to the teacher's right answer may be inhibiting to the development of students' independence and self-confidence (Kahn and Volmink, 1999). Investigational practicals based on problems to which students can relate to, needing students to personalise their knowledge and seeking to make sense of the world, will go a long way to develop mature and autonomous personalities sensitive to the resources and limitations of science. They pointed to the dangers of muddling together practical and theory so that the aims of each one are not distinguished. They argued that each - theory and practical - should be considered separately from the other so that a self-sufficient rationale might be established.

Swain, Monk and Johnson (1999) conducted a survey of the views of science teachers from Egypt, Korea and the United Kingdom (UK). The teachers were given the list of aims of practical work in science listed in Chacko (1997), and were asked to rank these aims according to their relative importance. The supplied aim no.7, "*to encourage accurate observation and description*", was ranked in the top five by all three groups. When the selected top ten aims were analysed, it was observed that each group included in their choices the aims numbered 2, 4, 8 and 12 (namely 2- *To make phenomena more real through experience*, 4- *To practise seeing problems and seeking ways to solve them*, 8- *For finding facts and arriving at new principles*, and 12- *To arouse and maintain interest*).

Swain et al. (1999) employed the questionnaire that had been developed and used by Beatty and Woolnough (1982) to gather data for their survey. They subsequently suggested that three more aims could be added to the list of aims:

- To reward pupils for good behaviour.
- To allow students to work at their own pace.

- To add variety to classroom activities.

They also reported on the conditions under which teachers from each country practised their teaching. Egyptian teachers worked in conditions of large classrooms and virtually no resources where the principal resource was the chalkboard. The Korean teachers worked in relatively opulent conditions compared to Egyptian teachers. They had well-equipped and well-resourced laboratories. Swain et al. interpreted the Korean teachers' responses as reflecting a positivist philosophy of science.

The UK teachers worked in comparatively well-equipped schools with laboratory facilities guaranteed. The teachers worked with practical activities for a significant proportion of their time. They reported that the UK teachers would apologize to visitors if there were no practicals in the lesson being visited.

They suggested that further work should be done to understand more about how local, national and epistemological environments interact and their relative contribution. They pointed to three areas that may be productive: a) it may be useful to see what opinions the three groups of teachers have on the aims of science education; b) ethnographic interviews could provide information on their cultural and professional opinions; and c) there is a need for detailed observation of the teachers' work in situ.

To achieve the content achievement aim of practical work, Okebukola and Ogunniyi (1984) made four recommendations for carrying out laboratory work in groups. These were:

- Co-operative laboratory work should be used by science teachers to improve the cognitive achievement level of students in science.
- Encouraging high ability students to work together in a group appears to be a good approach to improving their achievement levels.
- Rather than allow low ability students to work together in a group, allowing interaction with some average and high ability students in a

- mixed ability group will lead to improved performance of the low ability students.
- Mixed or heterogeneous ability grouping for cooperative work in the laboratory has a more facilitative effect on the achievement of low achievers than the competitive goal structure

Consequently, the practical items developed in this research will be designed in a way that they can be used collaboratively in class. If desired the learners can be asked to work in groups to develop several skills of the learners such as co-operation, following instructions, communication, application of their knowledge, observation etc.

Watts and Bentley (1989) emphasised the importance of active learning, but stated that doing practical work did not mean active learning. They argued that passive learning may have suited some learners, but usually it was ineffective for many learners. The active learning involved using different approaches to teaching. To involve learners more actively it may have been a better idea to have given them simple practical exercises or tests, and observe them. In this way several problems that the learners encountered might have been diagnosed. Usually the practical work was not organised by learners, but they had to follow step-by-step instructions, which meant that the learners did not own the activities. Pupils should have been given the opportunities to engage in experimental work in which a variety of practical and investigative skills were developed. Practical work was being seen as a way to encourage skill development and enable youngsters to test out their ideas about science (Watts and Bentley, 1989).

### **2.3. Science process skills and the theory of White (1988)**

Memory is believed to be at the core of learning. White (1988) suggested seven different elements of memory to describe the learning in science. The possible

relevance of these components of memory to the process skills involved in this research study is now analyzed and the practical tasks are classified.

### 1- Strings

Strings are sequences of words or symbols that are “given” and cannot be readily paraphrased. Physics laws and definitions such as “To every action there is an equal and opposite reaction” and “The angle of incidence is equal to the angle of reflection” can be considered as strings.

In the compact programme of practical activities investigated in the present study, a strings component of memory may be found to be relevant to items 2, 3, 4, 6, 7, 8, 9 and 10. (See chapter 3, Figures 3.2 to 3.10). For example ‘north pole attracts south pole’, ‘magnitude of current is the same at every point of a series circuit’, etc.

### 2- Propositions

Propositions are sequences of words or statements that describe properties of concepts or that draw relations between concepts. Unlike strings, propositions can be expressed in an equivalent form. For example  $D = \frac{m}{V}$  can be expressed as  $m = D \times V$  to calculate the mass.

Items 2, 3, 4, 6, 7, 8, 9 and 10 are intended to involve propositions such as

$$V = I \times R, P = \frac{F}{A}, P \text{ (power)} = V \times I \text{ etc.}$$

### 3- Images

Images are mental pictures. Strings and propositions can be seen as images. Images are not only visual but also related to all five senses. To imagine a special sound, or visualize words and concepts, are some examples for these.

Items 4, 5, 6, 9 and 10 are intended to involve images. The participants are required to imagine the interior size of a refrigerator, and the bulb used in a room, power and brightness of bulbs, etc.

#### **4- Episodes**

According to White “episodes are our records of experience, memories of events and occurrences we took part in or witnessed”. Only the episodes we bring to memory are available to us for a long time. An episode can be a real event, transformed event or an imagined event. Episodes are involved in items 2, 3, 4, 9 and 10. Participants may remember the times when they tried to burn a piece of paper by using a magnifying glass under the sunlight.

#### **5- Intellectual Skills**

Intellectual skills are “knowing how”, in contrast to propositional knowledge which is “knowing that”. Propositions are discrete facts, whereas an intellectual skill consists of knowing how to perform a series of related tasks. The acts of discriminating, classifying, and following rules are examples of three different forms of intellectual skills that are important in science. In all of the tasks of the current study intellectual skills are involved to different extents. Participants are required to know how to read instruments together with the scaling on the measuring instrument. They also need to apply the knowledge they learnt in theory (what) to actual practical questions (how).

#### **6- Motor Skills**

Thinking can occur while all the senses are in action. Using the microscope, balance, pipette, and burette all involve motor skills.

Motor skills are involved strongly in items 1, 3, 6, 7, 8, 9, and 10. The participants must be able to handle, use and make measurements with the actual

apparatus provided. They need to acquire certain motor skills in order to identify and use the apparatus properly.

### **7- Cognitive Strategies**

Cognitive strategies are general skills that we use in our thinking, learning and doing. In learning science we use general skills such as setting aims and goals, considering and working out different possibilities, choosing the best option, and generalizing across related contexts.

Cognitive strategies are found to be relevant to all of the practical test items in this study.

The analysis of the practical skills using White's theory of memory and the practical tasks' relevance will be discussed in detail in Chapter 4.

### **2.4. Scientific literacy and technological literacy and the public understanding of science**

In order to explain the term 'scientific literacy' in detail there are a number of different assumptions, interpretations, conceptions and perspectives of what the term means, what introducing the concept could achieve, and how it is constituted (Laugksch, 1999:3). Laugksch categorized the interest groups involved in scientific literacy into four parties. These are 1) the science education community; 2) social scientists and public opinion researchers concerned with science and technology issues; 3) sociologists of science and science educators employing a sociological approach to scientific literacy; and 4) the informal and non-formal science education community, and those involved in general science communication.

Laugksch (2000) presented a conceptual overview of the concept of scientific literacy. Scientific literacy was defined as what the general public ought to

know about science (Durant, 1993:129), and appreciation of the nature, aims, and general limitations of science coupled with some understanding of the more important scientific ideas (Jenkins, 1994:5345, both cited in Laugksch, 2000:71).

In this research the term scientific literacy is taken basically as the ability to place news of the day about systematized human knowledge in a meaningful context (Hazan and Trefil, 1990, and Branscomb, 1981, cited in Laugksch, 1999).

From the beginning, in the 1600s of the modern science era, there has been an interest and effort to close the gap between the content of academic science and the life world of the learner. Today this deficiency has become an international challenge for every nation because of the rapid change in the practice of science, revolutionary changes in societies and the emergence of the information age (Hurd, 1998). Hurd listed twenty-five attributes of a scientifically literate person, nine of which (bold) are emphasized in the present investigation. According to him a scientifically literate person:-

- **Distinguishes between experts and uninformed persons.**
- Distinguishes theory from dogma; data from myth and folklore.
- Recognises that almost every fact of one's life has been influenced in one way or the another by science/technology.
- Knows that science in social contexts often has dimensions in political, judicial, ethical, and sometimes moral interpretations.
- **Senses the ways in which scientific research is done and how the findings are evaluated.**
- **Uses scientific knowledge, where appropriate, in making life and social decisions, forming judgements, resolving problems and taking action.**
- Distinguishes science from pseudo-science such as astrology,

quackery, the occult, and superstition.

- Recognises the cumulative nature of science as an “endless frontier”.
- Recognises scientific researchers as producers of knowledge, and citizens as users of science knowledge.
- Recognises gaps, risks, limits and probabilities in making decisions involving a knowledge of science or technology.
- Knows how to analyse and process information to generate knowledge that extends beyond facts.
- Recognises that scientific concepts, laws, and theories are not rigid but essentially have an organic quality; they grow and develop; what is taught today may not have the same meaning tomorrow.
- Knows that science problems in personal and social contexts may have more than one “right” answer, especially problems that involve ethical, judicial, and political actions.
- Recognises when a cause and effect relationship cannot be drawn.
- Understands the importance of research for its own sake as a product of a scientist’s curiosity.
- Recognises when cultural, ethical, and moral issues are involved in resolving science-social problems.
- **Recognises when one does not have enough data to make a rational decision or form a reliable judgement.**
- **Distinguishes evidence from propaganda, fact from fiction, sense from nonsense and knowledge from opinion.**
- Views science-social and personal-civic problems as requiring a synthesis of knowledge from different fields including natural and social sciences.
- Recognises there is much not known in science fields and that the most significant discovery may be announced tomorrow.
- **Recognises that scientific literacy is a process of acquiring, analysing, synthesizing, coding, evaluating, and utilising**



achievements in science and technology in human and social contexts.

- Recognises the symbiotic relationships between science and technology and between science, technology and human affairs.
- Recognises the everyday reality of ways in which science and technology serve human adaptive capacities, and enrich one's capital.
- Recognises that science-social problems are generally resolved by collaborative rather than individual action.
- Recognises that the immediate solution of a science-social problem may create a related problem later.
- Recognises that short- and long-term solutions to a problem may not have the same answer (Hurd, 1998:413-414).

Miller (1983), cited in Laugksch and Spargo (1996:122), suggested that the concept of scientific literacy consists of three dimensions: an understanding of *norms and methods of science* (i.e. the nature of science); an understanding of *key scientific terms and concepts*; and an awareness and understanding of the *impact* of science and technology on society. The present investigation is concerned mostly with Miller's second dimension.

Baker (1991) presented a summary of research in science education for 1989 and organised the summary around 14 major themes, such as computers, curriculum, misconceptions, scientific literacy, etc. In the part of his summary on scientific literacy he concluded that scientific literacy is part of cultural literacy and consists of the skills and knowledge that allows a person to live in a technological age. He also pointed out that scientific literacy was linked to the curriculum and how teachers present science. Therefore the way the science teachers present science has an important role in the degree of scientific literacy

of learners and the broader community. In this research a practical approach to teaching and assessment in science is utilized and suggested.

Jenkins (1994:601-611) examined the terms “public understanding of science” and “science education for action”. According to him, much research in the area of the public understanding of science presented a picture of scientific literacy, and the concern over the scientific literacy of the public spawned many publications. Eventually “scientific literacy for all” has become a slogan for science curriculum reform and innovation in many countries.

Of particular relevance to the present study is the work of Cajas (1999:765) who discussed the use of school science in the students’ everyday lives as one aspect of the public understanding of science. He argued that the goal of connecting school science with students’ everyday lives moves the discussion of the public understanding of technology. He also stated that technological knowledge is an important element that can help us to connect school science with students’ everyday lives. Thus, in the practical items used in this research, some examples of applications of science and technology in everyday life are involved.

Jenkins (1994) argued that the slogan “scientific literacy” must be changed to “science for action”. He stated that *science education for action* demands a rationale which is fundamentally different from that which underpins science curricula traditionally offered by schools and colleges. Scientific knowledge in the context of action is essentially about *empowerment*. It follows, therefore, that institutional provision, curricula, pedagogy and, where required, assessment must all be directed towards this end. The assessment action strategy used in this study could be used as a tool of empowering the students’ learning in science classes as it can provide feedback on the process of teaching and learning.

Solomon (1998) described a comprehensive theory of the multiple dimensions of the public understanding of science. She looked beyond the content of the school science curriculum, and beyond practical work in school laboratories. Among other things, she highlighted the *wider importance of science* in everyday life and in social settings. She moved the context of learning science into the home; she engaged economics and science; and she linked the learning of science with the employment of trained technical experts in the labour market and vocational and core communication skills to prepare pupils for relevant careers needed by industrialists in a diversity of linguistic and cultural traditions. Finally, she focused on science for the development of the individual pupil, encouraging the growth of independent learning skills such as creativity and curiosity. The following categories, themes and indicators may be drawn from Solomon's paper:

- Science for the personal development of the individual by enhancing his/her
  - life skills
  - vocational skills
  - communication skills
  - citizenship skills
  - long-term values
  - personal growth, feelings and emotions.
- Science as a requirement of a specific profession or vocational board/body.
- Science for its own rational development
  - as a logically structured set of concepts, theories, processes, skills, evidence, knowledge and limitations
  - as a development of historical events.
- The humanistic utility of science
  - for societies' needs
  - for the economic development of a nation with a specific

reference to

- better health
- the environment
- social reconstruction
- science for the work place
- ethical dilemmas
- the international future competitive edge
- mobilization for informed, motivated and substantive social change
- cultural transmission of knowledge
- adaptable, novel retraining of the workforce.

These categories, indicators and themes of public scientific literacy identified by Solomon will be used to classify and analyze the practical items, where possible.

Pella, O'Hearn and Gale (1966), cited in Laugksch (2000:76), studied the literature published between 1946 and 1964 and determined the frequency of occurrence of "referents", i.e. terms that were assumed to be related to scientific literacy. They concluded that a *scientifically literate individual* has an understanding of: a) the interrelationships of science and society; b) the ethics that control the scientists in their work; c) the nature of science; d) differences between science and technology; e) the basic concepts in science and technology; and f) interrelationships between science and humanities. The understanding of different concepts in science through their simple practical applications are involved in the practical test items used in this study.

Shen (1975a), cited in Laugksch (2000:77), suggested three categories of scientific literacy: *practical, civic and cultural* scientific literacy. **Practical scientific literacy in this context meant the possession of the kind of scientific knowledge that can be used to solve practical problems.** Therefore this present study will attempt to develop practical test items that could possibly be useful as a means of investigating components of practical scientific literacy advocated by Shen.

Shen (1975b), cited in Laugksch (2000:77), also stated that in industrialised countries practical scientific literacy could well be useful in *consumer protection efforts*. Branscomb (1981), cited in Laugksch (2000:77), examined the Latin roots of the concept scientific literacy and defined the concept as the ability to read and write systematized human knowledge. Branscomb (1981:77) identified eight categories of scientific literacy: a) methodological scientific literacy; b) professional scientific literacy; c) universal scientific literacy; d) technological scientific literacy; e) amateur scientific literacy; f) journalistic scientific literacy; g) science policy literacy; and h) public science policy literacy.

Hazen and Trefil (1990), cited in Laugksch (2000:80), distinguished between *doing science* and *using science* and stated that scientific literacy only concerns using science. They also believed that a scientifically literate person should be able to place the news of the day in a meaningful context. For the general public using science has a greater importance than doing science. Thus it could be argued that school learners should be exposed to different ways of using the applications of science and technology in their everyday lives.

Shamos (1995), cited in Laugksch (2000:80), proposed three forms of scientific literacy. The first form is *cultural* scientific literacy and it is the level of scientific literacy held by most educated adults. The second form is *functional* scientific literacy. This requires that the individual not only has a command of scientific vocabulary but also is able to converse, read and write coherently in a non-technical but meaningful context. The third form of scientific literacy is *true* scientific literacy. This is the most difficult to attain as it involves, in addition to other forms, also knowing something about the scientific enterprise. The school science teaching can contribute to these levels of scientific literacy at different levels.

Laugksch (2000:82) classified the interpretations of scientific literacy into three categories: “Learned”, “Competent”, and “Able to function minimally as consumer and citizen”. He included sixteen interpretations of scientific literacy and there were five, five and six interpretations in each category respectively.

Laugksch (2000:83) suggested two features of this summary scheme, described above. The first is related to the relative or absolute nature of the scientific literacy concept. The learned and competent categories are defined in an absolute sense whereas the third category is defined with reference to functioning effectively in society, i.e. relative to society.

The second feature of this scheme is the extent of involvement in and with society. Conceptions in the learned category specify no involvement whereas definitions in the competent category require at least some form of interaction. The definitions in the third category require the individual to use science in performing a function in society.

Laugksch (2000) studied the importance of scientific literacy at the *macro* and *micro* levels. He stated that, at a macro level, the connection between scientific literacy and the economic well being of a nation is accepted to be of a high importance. At a micro level the argument that improved understanding of science and technology is advantageous to anyone living in a science and technology dominated society explains the importance of scientific literacy.

Laugksch (2000:87) pointed out that there are different definitions of scientific literacy. He presented these differences in terms of methodologies used by the interest groups he identified: the sociological approach; public opinion researchers and science educators.

Technology is also an intrinsic part of a cultural and social system. It both shapes and reflects the values of that particular system. It is not only a matter of

research, design and craft but also of economy, production, management, labour, marketing and maintenance. Science For All Americans on-line (1997) queried which knowledge about the nature of technology is required for scientific literacy. It arranged the ideas into three sections: 1- the connection of science and technology; 2- the principles of technology; and 3- the connection between technology and society.

It is stated that, as technologies become more sophisticated, their links to science become stronger. Engineering is defined as the component of technology which is most closely allied to scientific inquiry and mathematical modeling. Scientists see patterns in phenomena as making the world understandable; engineers see them as making the world manipulable. Scientists try to show that their theories fit data; mathematicians seek to show logical proof of abstract connections; engineers seek to demonstrate that designs work.

Engineering has salient importance in the economic development of a country. Schacht (1995:133) highlighted this, and stated that the engineering profession had a big part in implementing the Working Nation strategy of Australia, and engineering educators had an important role in helping the profession to achieve this objective.

Wald (1999:1) stated that in some countries such as Israel and Ireland that were experiencing large GDP growths, the need for engineers and their future prospects were booming. He pointed out that the availability of skilled and educated human resources brought the high-tech investment, and he concluded that a shortage of highly skilled technical personnel threatened.

One aspect of engineering education that would produce the kind of engineers needed by industry and the workplace would be to make research-based learning the standards. Wald (1997:389) stated that a theoretically schooled engineer should also be practically inclined and should be exposed to problem-

based learning which has the capacity to improve the skills needed by an engineer to solve real life problems. Thus, it is possible to distinguish between the notion of technological literacy and the concept of scientific literacy.

## **2.5. Studies of scientific literacy**

In 1995, approximately 25% of the population of the United States was described as functionally illiterate and 90% as scientifically illiterate. The percentages may vary from country to country but the main issue still prevails in all countries. Therefore the investment in education must be meaningful, it must be applicable to the daily lives of students, and they must be made active in learning science (Kyle, 1995:1009).

In the Third International Mathematics and Science Survey (TIMSS) the surveyed sample of 15000 South African school students did not perform well compared to the other countries. Howie (1997) reported the results of the survey on the South African students in comparison with the other countries that took part. A questionnaire was conducted to gather information about the attributes of the students. Some of the findings were

- The average age of population 3 (final year) school students was 20.1 years in South Africa, but it was 17-19 years in other countries.
- 85% of the South African final year high school students enrolled for biology and 70% of these included mathematics.
- 95% of the school students had intentions of studying further and 75% of these planned to go to a university. The most popular area of anticipated study for the South African students surveyed was engineering, followed by business.
- The students preferred biology to physics and chemistry.
- The majority had parents with primary school as their highest attained educational level.



- 60% reported that they had fewer than 26 books at home. In other countries this percentage was 3-23%.
- 92% did not have a computer; 81% never or rarely used a computer.
- South African students spent an average of five hours a day on homework but did not improve their achievement in this survey. In other countries this homework figure was 1-3 hours.

The following conclusions were derived from the achievement scores of the South African mathematics and science students who took part in this review.

- Their overall scores were significantly lower than those of students from other countries. This was ascertained by comparing students' responses to test items focusing on science and mathematics problems applied to the real world.
- ✓ • The sample of South African students struggled with constructing their answers, since they performed very poorly on items when responses had to be generated creatively in English.
- ✓ • Home language might have had an effect because the majority of South African students surveyed did not have English as their mother tongue.
- ✓ • The students with English and/or Afrikaans as their mother tongues performed significantly better than those with other mother tongues.
- No difference was found between boys' and girls' achievement scores. In other countries boys performed better than girls.
- Students from the provinces of Free State, Gauteng, and KwaZulu-Natal performed better than students from other provinces.
- South African students achieved relatively better in mathematics than in science.

As stated in the first finding of TIMSS above, the South African students did not perform well in the items related to the real world. This suggests that the

use of actual everyday components (concrete apparatus, real life problems, etc.) may be important in learning science.

The above study was repeated in 1999. The Third International Mathematics and Science Study-Repeat (TIMSS-R) in South Africa included 8147 Grade 8 learners from 194 schools. In the executive summary by Howie (2001), it is stated that the results of this research were generalizable to each province as well as to the whole country. The questions central to this study were:

- What are the students expected to learn?
- Who provides the instruction?
- How is instruction organised?
- What have students learned?

Data collected in this study was divided into three categories; 1- the curriculum; 2- achievement; and 3- contextual data from principals, teachers and pupils. In the study, South African participants were exposed to questions that were specific to the South African context.

In both science and mathematics, South African learners scored significantly below the international mean scores. Western Cape learners scored the highest among the provinces but this was still significantly below the international mean score. Some of the findings of this study are listed below:

- Only 0.5% of South African Grade 8 students reached the international top 10% benchmark.
- The bottom 5% of South African Grade 8 high school students had a mean score of 53 out of 800.
- The mean score of students from the Western Cape was significantly above the mean scores of other provinces, but this was significantly below the international mean score.

- Although there was no significant difference between the overall science scores of boys and girls, significant differences were found in specific content areas: Earth Sciences and Physics. Boys scored 3% higher for Earth Sciences and 5% higher for Physics.
- South African learners seemed to do better in the items that related to basic knowledge about the earth's features and human biology, and those they could relate to everyday experiences.
- ✓ • Learners had trouble with the interpretation of tables and graphic representations. ✓
- The overall average of South African students decreased in both mathematics and science by three scale points compared with TIMSS in 1995, which was not significant.
- Internationally a major emphasis in science is given to knowing basic science facts and to understanding science concepts. However South Africa placed only a moderate emphasis on these aspects.
- 45% of principals reported that lessons at their school were hampered by the shortage of instructional materials and 31% by inadequate space.
- ✓ • 38% of science teachers involved in this study had no formal qualifications in science.
- ✓ • Only 26% of pupils spoke the language of the test as their first language and these performed better in both mathematics and science.
- ✓ • About half of the teachers did not feel competent in the content of either science or mathematics. ✓

As stated in the above findings, it seems important that learners be encouraged to make connections between school science and their everyday experiences. In general South African learners scored significantly lower than their international counterparts. One of the implications of this result might be that the traditional "textbook and writing board only" approach to science and

mathematics teaching, learning and assessment be reconsidered to introduce new and innovative practices.

Turner and Sullenger (1999:5-27) identified *three competing movements for the reform of science teaching*. They also analysed some of the deep assumptions about the relationship between research science, school science, and children's learning. They pointed out that science studies encouraged the belief that science education must be *about* science as well as being *in* science. They stated that science educators have been influenced by the literature of science studies. However, science educators have used the literature selectively, as one resource among many, choosing only one that fits their commitment, ignoring other elements, and occasionally distancing themselves altogether. When required to use practical components, it is reported that the teachers usually may not involve their learners in actual practical work. This will tend to occur if they lack either the necessary resources or the required training. The fact that ✓ 38% of the science teachers involved in TIMSS-R by random selection had no formal qualifications in science may be the case for many other schools in South Africa.

According to Turner and Sullenger (1999), the educational literature has often embodied the deep cultured tenet that science education succeeds best when it immerses students in the activities and methods of research. Educators must not shrink from hard negotiation over what will count as an understanding of science or from their obligation to devise humane and socially responsible methods for promoting that understanding. Finally, they concluded that scientists need to be better informed about the educational debates over science teaching. Thus, in chapter 5 of the present study, the claims of Turner and Sullenger (1999) will be discussed more comprehensively in the light of the data collected and presented in the current investigation.

## **2.6. Specific content areas of science teaching**

### **2.6.1 Electricity: cells, resistors, bulbs, current, voltage, wattage, circuits etc.**

In England, Black, Solomon and Stuart (1986:185) investigated the awareness of electricity of 241 11-12 and 13-14 years old pupils, and they found that 61% of the 11-12 years old and 35% of the 13-14 year old pupils could mention the dangers of electricity. They concluded that the pupils created meaning for the scientific concepts through their personal daily lives. ✓

In the USA, Carter, Westbrook and Thompkins (1999) studied the use of scientific tools and equipment to mediate learning about circuits. They reported that the tools they believed would mediate learning did not. They interpreted this and stated that the tools were not selected from the zone of proximal development of students. They also observed that male group members tended to dominate equipment usage while girls were less likely to establish ownership of the laboratory materials. The familiarity of the learners with the apparatus used in the classroom was also an important issue. Thus it is important that the practicals that are used in science teaching be selected from the ones with which the learners have some familiarity. This present research therefore attempts to find out the degree of familiarity of the South African learners with the apparatus used in the practical items.

An underlying idea that many learners bring with them at the beginning of formal studies is that there is a 'source' of electricity, the battery, and a 'consumer' of electricity, the bulb (Shipstone, 1985: 35). Joshua (1984) found that learners rarely introduce the notion of potential difference in their discussions about electrical circuits. ✓

Hendricks (2001) reviewed the literature on the learning difficulties that learners encounter in electricity and drew the following conclusions: ✓

- ✓ • Some students believe in the unipolar model. They regard only one terminal of a battery as being active (Fredette and Lochhead, 1980; Jabin and Smith, 1994).
- ✓ • Some students believe that current leaves the battery from both terminals, moves around the circuit and clashes in the bulb, causing it to light up (Osborne, 1981; Jabin and Smith, 1994).
- ✓ • Some students believe current flows around a circuit in only one direction; and that current leaves the battery from one terminal and gradually becomes weakened as it moves along, so that the later components receive less (Shipstone, 1982; Jabin and Smith, 1994).
- ✓ • Some students propose that in a series circuit, current will be shared equally by all of the components (Shipstone, 1982).

Regarding currents in branching circuits, popular alternative conceptions include the following:

- ✓ • Current flowing from a battery is constant and is not affected by changes in the external circuit (Stanton, 1990).
- Current has no 'knowledge' of what lies ahead in a circuit. It follows a linear path around the circuit. It departs from the battery and then first encounters one resistance before it encounters a second. In fact, some learners believe that current is 'used up' by various circuit components that it encounters along its path (Moodie, Bashe and Watson, 1995; Solomon, 1980). This is often referred to as the consumer model.
- Current will divide into two equal parts at a junction, regardless of the magnitudes of resistors in parallel that might be present beyond the junction (Stanton, 1989).

Regarding voltages in circuits, learners:

- Find great difficulty in discriminating between current and voltage (Evans, 1978).
- Confuse cause-and-effect, believing that voltage is dependent on current flow, and cannot comprehend why a potential difference can be maintained over a gap in the circuit (Shipstone, 1985).

In addition to these erroneous ideas, students tend to over-generalise simple electricity sample problems in physics texts and then apply these overgeneralizations to new complex problems with negative consequences. Stanton (1989) expresses the following concern directed at the impending danger of teaching students only special cases without informing them that these are not the only cases that exist. The following excerpt is representative:

The writer notes with concern that in the proposed new (South African) core syllabus, there is the suggestion that parallel circuits be restricted to special cases where the resistors are equal. (Stanton, 1989: 6)

Extensive research by Evans (1978), Fredette and Lockhead (1980), Osborne (1981), Joshua (1984), Shipstone (1985), Stanton (1989) and Jabin and Smith (1994), among others, clearly indicates that the teaching of abstract concepts makes the topic of electricity a 'minefield' of alternative conceptions. Shipstone (1985), in his chapter on 'The alternative electrical concepts exhibited by young children', summarises the problem as follows:

Electricity is a difficult subject. Children are asked to reason in terms of abstract notions such as current, voltage and energy. They find it difficult to differentiate between the concepts in this subject area. (Shipstone, 1985: 33)

As stated earlier, students' alternative conceptions have been shown to be very difficult to uproot. Gerace (1992) maintains that these notions are retained even after concerted efforts have been made to dislodge them. He advises that one needs to know about these alternative conceptions held by students before pointing out their flaws or inducing them to reformulate their world-view (Gerace, 1992: 30).

### 2.6.2 Mechanics

Gilbert and Zylbersztajn (1985) studied the concepts of force and movement in terms of interactions between scientists' science, curricular science, teachers' science and children's science. They divided the conceptions concerning force and movement historically into three major groups: the 'Aristotelian view'; 'the impetus theory'; and 'the inertial view'. They stated that the conceptions of students could be examined in terms of these three perspectives. They argued that the sequence of presentation of the concepts of force and movement was based on assumptions which were warranted neither by the history of science nor by research on children's science. As a result of this, a superseded view on the nature of scientific knowledge was conveyed to the students.

Gilbert, Watts and Osborne (1982: 65) stated that children's prior ideas had not been considered sufficiently in the development of the curricula. They presented three alternative approaches to curricula:

- 1- The blank minded tabula rasa assumption: which assumes that learners come to the classroom with a blank mind and the teacher fills everything into that blank mind.
- 2- The teacher dominance assumption: when children bring their own ideas but the teacher changes these ideas through formal teaching, and the students change their views.
- 3- The student dominance assumption: when children come with their own ideas which are sometimes resistant to change, and an interaction between the children's ideas and teachers' views occurs.

The results of the present research might yield some evidence on the nature of formal science teaching that is happening at some schools. The practical items have been selected from the syllabus topics with which the participants would be familiar with, i.e. which have been taught to them in their science classes.



In South Africa, Enderstein and Spargo (1998) investigated the effect of the context in which questions in mechanics were exposed to students and the intuitive beliefs of students in the Western Cape and Transkei. They found that the *context* of a question has a clear effect on frequency of choosing different options in physically similar situations. They argued that the context of the situations used to explore the students' alternate conceptions about particular concepts in physics has very rarely been taken into account but it has great importance (p 725). Thus, in one of the practical activities to be investigated in the present study, shoes from different contexts (formal, soccer and running) will be introduced for item evaluation.

One of the findings of Enderstein and Spargo's (1998) research was that students had problems in accepting the fact that a surface can exert a force on an object. They observed that students were more aware of the upward acting force when a human holding an object was involved. They suggested that teachers of physical science should study and observe the activities (games etc.) in which students involved during their early childhood and should include similar situations to demonstrate related concepts in physics.

Galili and Bar (1992:63) stated that the relation between force exerted on a body and the nature of its movement is one of the fundamentals of any introductory physics course at any level. They argued that, although long discussions have taken place on the subject, it still remains a living problem in teaching physics. They stated that the "motion implies force" preconception is usually caused by the context of qualitative questions and by situations of non-zero acceleration, especially when force and velocity are not parallel.

Galili and Bar (1992) studied the understanding of force-motion relationships of high school and college students and pre-service teachers in a Technology Teachers College. They reported that pre-instructional high school students and the pre-service teachers had a high level (43% and 78% respectively) of pre-

Newtonian views of force and motion. Pre-service teachers showed a higher rate of confidence with only 17% “don’t know” answers.

### **2.6.3 Optics**

Redish (2000) presented several findings about teaching optics and light. He stated that understanding images formed by mirrors and lenses is one of the topics with which learners usually have difficulties. He also reported that many students at university level do not understand basic issues with lenses. For example, some of the incorrect ideas that dominate the students’ views about the real image of a bulb formed by a lens are: 1- removing the lens will make the image right side up (45%); 2- the image does not lie on the screen (75%); and 3- covering half a lens will block half of the real image (75%). He argued that, after mechanics, optics is an area of physics in which a great deal is known about what difficulties students have learning it. He also stated that modern research-based instructional methods have proven to be effective in teaching optics.

Pompea and Stepp (1995) pointed out that everyone is affected by science in a modern world, therefore every citizen should be aware of scientific issues and have at least a basic understanding of scientific principles. They stated that optics is usually thought of as a senior or graduate-level class. They argued that optics is a very demonstrable topic and it can be taught in different ways at all grade levels. They added that the students must have an idea of optics before they are taught fundamental concepts and they must be given an opportunity to play with optics. They argued that many people think that a pair of binoculars or a camera is magic, because they have never seen the interior of these items of equipment and they cannot name their parts.

### **2.6.4 Discussion**

After the findings of the current study on students’ basic process skills in the topic areas electricity, magnetism, mechanics and optics have been presented in

chapter 4, the discoveries made with the students in Cape Town will then be compared and contrasted with the earlier findings disseminated in the literature reviewed above, and linkages will be established where possible.

### **2.7. Methods of teaching everyday science**

Mayoh and Knutton (1997:849) reported a classroom-based participant observation study of 103 science lessons which focused on the use of examples of out-of-school experiences by both teachers and pupils. They observed 103 science lessons and noted and analysed 215 episodes of references to out-of-school experiences. Talk with teacher was involved in 69% of these episodes.

By qualitatively analysing the data they identified twelve major themes:

1. Referring to mass media.
2. Referring to personal experience: telling stories.
3. Referring to common out-of-school experiences.
4. Referring to uncommon out-of-school experiences.
5. Referring to common objects.
6. Images from out-of-school experience.
7. Referring to everyday knowledge.
8. Referring to everyday words.
9. Using analogies and metaphors based on everyday experience.
10. Using everyday contexts for classroom activities.
11. Developing skills for use in everyday life.
12. Referring to industry.

They concluded that the key to improving science teaching and learning was through raising the awareness of teachers of common practice in science classrooms and through encouraging teachers to reflect upon the everyday significance of their classroom actions and communication.

As it can be observed easily from this list, teachers tended to use everyday experiences of learners during formal science teaching. This may imply that the teachers believed in the effect of bringing examples of everyday reality into the

classroom. Hence apparatus selected and used in the practical test items adopted in the present study, will be involved in most students' everyday lives.

Cajas (1999) commented on the work of Mayoh and Knutten (1997) and interpreted their data. He stated that the relevance of formal science teaching to the learners' everyday lives has always been accepted as an important goal; however, it has rarely been studied. He pointed out that there was a lack of research in this area. The current study therefore emphasizes the involvement of learner' everyday experiences in formal teaching and records some of the incidental attitudes of learners towards this phenomena.

Carter, Westbrook and Thompkins (1999) reported the results of research which invoked a Vygotskian framework to examine students' use of science tools in a ninth-grade physical science classroom. They conducted the study in the context of a unit on electric circuits. Having analyzed the data through a framework of social cognition they made four claims: a) students who were able to verbally relate the tools to everyday experiences perceived themselves - and were often perceived by their group - as tool experts; b) physically using the tools was a necessary prerequisite for using the tools as mediators of learning; c) boys initially dominated the use of tools; girls who demanded use of tools indicated an awareness of the importance of the tool usage for mediating understanding; and d) if the tools were outside their zones of proximal development, students could not use the tools to develop an understanding of the circuits.

Hence, the participants in the present study will be allowed hands-on interaction with the actual apparatus provided so that it will give them a better opportunity to reflect on the concepts involved and the questions presented to them.

Osborne (1997:61-66) suggested four alternative ways to teach science: 1) working in small groups; 2) discussion of instances/misconceptions; 3) jumbled

sentences; and 4) false concept maps. He stated that improvements in science education are most likely to come from making an important distinction between *doing* science and *learning* science, the former being necessary to discover and establish new knowledge of the natural and living world. Osborne argued that practical work is only one strategy from an extended preparation of a science teacher. These two notions of doing science and learning science may be combined as "*learning science through doing science*".

Whitelegg and Parry (1999:68-72) examined the issue of learning physics content, in the particular context of energy, through real life contexts. They introduced two projects, one from the UK and one from Australia. They emphasized the importance of selecting appropriate context and described it as vital. They also examined a variety of meanings of context-based learning and concluded that the term context-based learning describes many different approaches. Finally they pointed out that it must be a requirement of a context-based learning programme that students are able to transfer learning concepts between contexts.

Driver and Oldham (1986:105) identified three theoretical developments which suggested the rethinking of teaching and learning science: the identification of children's ideas; the constructivist view of learning; and learning as conceptual change.

These three points should be taken into consideration when new methods of teaching science are being developed. For certain practical items in the current study, participants will be required to link their theoretical knowledge from the science classroom to their first-hand experiences in their everyday lives.

During the 1990s one of the emergent trends predicted to impinge on developing countries was that technology would form a new focus of interest in

the curriculum, with an increasing emphasis on the skills needed to solve real life problems.

In South Africa, Outcomes Based Education is currently being implemented in the schools, universities and technikons. In Curriculum 2005, Technology was named as one of eight learning areas, as well as Natural Sciences, Literature and Languages, Human and Social Sciences, Art, Mathematics, Life Orientation and Economic and Management Sciences. Seven specific outcomes were adopted for the learning area Technology. These outcomes were listed as follows (Department of Education, Policy Document: Senior Phase, 1997:Tech 3):-

1. Understand and apply the technological process to solve problems and satisfy needs and wants.
2. Apply a range of technological knowledge and skills ethically and responsibility.
3. Access, process and use data for technological purposes.
4. Select and evaluate products and systems.
5. Demonstrate an understanding of how different societies create and adapt technological solutions to particular problems.
6. Demonstrate an understanding of the impact of technology.
7. Demonstrate an understanding of how technology might reflect different biases and create responsible and ethical strategies to address them.

The following specific outcomes were adopted for the learning area Natural Sciences (Department of Education, Policy Document: Senior Phase, 1997:NS 6):

1. Use process skills to investigate phenomena related to the Natural Sciences.
2. Demonstrate an understanding of concepts and principles, and acquired knowledge in the Natural Sciences.
3. Apply scientific knowledge and skills to problems in innovative ways.
4. Demonstrate an understanding of how scientific knowledge and skills contributes to the management, development and utilisation of natural and other resources.
5. Use scientific knowledge and skills to support responsible decision-making.
6. Demonstrate knowledge and understanding of the relationship between science and culture.

7. Demonstrate an understanding of the changing and contested nature of knowledge in the Natural Sciences.
8. Demonstrate knowledge and understanding of ethical issues, bias and inequalities related to the Natural Sciences.
9. Demonstrate an understanding of the interaction between the Natural Sciences and socio-economic development.

Curriculum 2005 has been restructured recently and the changes that were made to Curriculum 2005 are presented in the latest released Revised National Curriculum Statement Draft (2001). Different from Curriculum 2005, the Learning Area Natural Sciences has been divided into four main strands and the nine learning outcomes of the learning area have been replaced with the following three outcomes (p 18):-

1. The learner is able to develop and use science process skills in a variety of settings.
2. The learner is able to develop and apply scientific knowledge and understanding.
3. The learner is able to gain an appreciation of the relationship and responsibilities between science and society.

The four main strands into which the Natural Science Learning Area has been divided are: 1- Life and living; 2- The Earth and beyond; 3- Matter and materials; and 4- Energy and change (p 17).

Thus, in the present study, the practical test items will be classified according to the outcomes of learning Natural Science described in the latest revised Revised National Curriculum Statement Draft.

## **2.8. Assessment in science teaching**

This section investigates several issues around assessment practices in science education. Champagne and Newell (1992:841) stated that American science students did not do well in the international comparisons on tests of scientific literacy. They blamed multiple choice type tests and their focus on isolated facts. In their article they laid out an agenda for developing assessment tools

and research questions for each task. Finally they concluded that assessment was a highly political process and a critical issue in today's education world. Therefore, when assessment is planned, the aim and the relevance of the assessment, content and method to the desired outcomes should be determined.

Sutherland and Peckham (1998:98) identified three characteristics of higher education in South Africa:

- Large classes,
- Disadvantaged learning backgrounds, and
- Limited administrative assistance.

They looked at the assessment practices and discussed different methods such as continuous assessment, computer aided assessment, collaborative assessment, use of assignment attachments and authentic aspirations in the light of the new South African Qualifications Authority (SAQA) Act. They stated that many students saw assessment as a discriminatory exercise rather than as an opportunity to enhance their skills and knowledge. The SAQA bulletin (1997:100) stated that *assessment must be a tool for learning*. Therefore the practical items developed in this study may also be given to the students and subsequently they may be allowed subsequently to compare their ideas with the correct responses. In this way, they may have an opportunity to measure their own level and worth.

Sutherland and Peckham (1998:100) also stated that, if it is necessary to inculcate life long learning, the students must be trained to assess their own worth.

They also compared the "traditional" and the "alternative" assessment paradigms suggested by SAQA and reproduced in Table 2.1. However, perhaps it could be argued that good teachers have always used aspects of both types of paradigm, so the distinction appears to be an artificial or contrived one.



Table 2.1: The traditional and alternative assessment paradigms.

Traditional paradigm	Alternative paradigm
Summative focus (for grading)	Formative focus (for learning)
Judgmental in nature	Developmental in nature
Focuses on content	Focuses on the learning process
Teacher-led assessment	Student-led assessment
Separate from course design	Perspective of the curriculum
Isolated from learning process	Integral part of the learning process
Reliance on examinations	Variety of methods
Implicit criteria	Explicit criteria
Norm-referenced criteria	Self-referenced or criterion-referenced criteria
Over-emphasis on memory and lower order of thinking skills	Emphasis on critical thinking and higher order thinking skills
Encourages surface learning	Encourages deep learning
Decontextualised assessments	Authentic assessment practices

They concluded that, to maximize the positive effects of assessment, it would become necessary for some staff to review their assessment practices, and educators must acknowledge that assessment is based on human judgment and not pretend that it is an accurate, rigorous, objective and scientific exercise.

The principles of assessment in Outcomes Based Education are summarized under ten points in the Assessment Workbook published by the Western Cape Education Department (WCED) (May 2001:4):

- 1- Assessment is transparent.
- 2- Assessment is criterion-referenced.
- 3- Assessment assists learners to reach their full potential.
- × 4- Assessment involves a shift away from learning as memorization.
- 5- Assessment involves learners actively using relevant knowledge in real-life contexts.
- 6- Assessment is continuous.
- × 7- Assessment focuses on knowledge, skills, attitudes and values and not only on the content.
- × 8- Assessment is diagnostic, enabling the teacher to monitor strengths and to address the needs of learners.
- × 9- Assessment covers a wide spectrum of learning activities and tasks.
- 10- Assessment enables teachers to pace learners and to provide enrichment for fast learners.

The Learning Area Natural Sciences (NS) has been re-defined recently, and its purposes and specific outcomes have been presented in the latest Revised National Curriculum Statement Draft (2001). The characteristics of the *assessment* in NS have been summarized as follows:-

- 1- Transparent, democratic, clearly focused and participatory.
- 2- Integrated with teaching and learning.
- 3- Based on pre-determined criteria or standards.
- 4- Integrated, in making use of integrated tasks and activities, and a variety of methods, tools, techniques and contexts in assessing learner's performance.
- 5- Valid, reliable, fair, learner-paced and flexible enough to allow for expanded opportunities (p 73).

It is stated that assessment in NS has two main purposes; to monitor the progress of learners and to facilitate learning so that they can reach their potential (p 74).

It is observed from these statements that, in an OBE medium, assessment will not be a discriminatory process that is used to determine who passes and who fails, but it will be used as a tool to facilitate and stimulate learning. The new draft document also encourages the learners to involve themselves in their assessment.

Continuous Assessment is the assessment model that is recommended in the National Curriculum Statement Draft Document because it covers all OBE assessment principles. Continuous Assessment can be used for five purposes (pp 76-77):

- 1- Baseline assessment: to establish what the learners already know.
- 2- Diagnostic assessment: to find out about the nature and the causes of the learning difficulties experiences by learners.
- 3- Formative assessment: to monitor and support the process of learning.

- 4- Summative assessment: to provide an overall picture of the learner's progress at times when an overall progress report is needed.
- 5- Systematic evaluation: to assess the education system at regular intervals, carried out at national level.

The types of practical items used in this study could be widely utilized for the first four purposes by changing the levels of the items. From each one of these items simpler and more complex items could be developed and used for different purposes.

A cycle of planning of teaching and assessment is explained through a diagram in the Assessment Pack 1 by the Western Cape Education Department (2001:4). This cycle considers assessment as a tool that should reflect on the teaching and learning process.

The national Senior Certificate Examinations Guidelines document (2001:3) stated that 30% of the Higher Grade (HG) and 15% of the Standard Grade (SG) examination in Physical Science should focus on application problems and their explanations.

There has been a need for a complementary programme to be developed to investigate the practical scientific literacy of the learners and teachers, across a wide range of topics in science. As a result of the lack of practical work, many learners have perceived school science as abstract and having no relation with practical life.

Consequently, in the present study, a programme is being developed to assess the practical scientific literacy levels in selected areas of school-level physics in the South African context.

## 2.9. Teacher training and science practical work

Bekalo and Welford (1999) reported their findings of a research study focused on teacher education. They studied the experiences of student-teachers' pre-service science education regarding practical work in Ethiopia. They stated that secondary teacher education consists of a) academic courses and b) methodology courses.

They reported that the traditional practical work was perceived by tutors and students as a set of routine activities for arriving at a pre-determined solution by following detailed instructions. Tasks involving more open-ended investigations were not observed during their survey. There was no practical activity observed in any of the sessions they visited. They quoted the opinions of a teacher-trainer who stated that they were pure physics, chemistry and biology graduates and they had not taken enough educational courses.

They argued that teachers did not attempt to organize practical work in schools, even when there were conducive classroom settings and reasonable resources, because they did not know how to! Especially in the TIMSS-R (2001) results it has become obvious that South Africa is experiencing a problem of underqualified science and mathematics teachers.

Bekalo and Welford (1999:1307-1308) made recommendations regarding practical teacher training under five headings:

1. A balance between the curriculum load and the credit given to academic and pedagogy courses.
2. Broadening the scope of the practical work. They argued that the existing emphasis restricts the range of possible strategies available for promoting practical work.
3. Emphasis on school curriculum and settings.
4. Examination and assessment: the current examination strategy does not test fully the scientific and pedagogical activities and skills.
5. Enhancing the competence of educators. Teacher training institutions are required to review and develop their staff's specialism.

In South Africa similar problems might be experienced due to the current situation of teacher qualifications and training. One of the emerging issues in the new revised Curriculum 21 draft document is the training of the educators. Potenza (2001:4) presented a curriculum reform timeline in South Africa which showed that new training of teachers will start and continue in the near future.

Also, very few science and mathematics teachers were over 40 years old, suggesting that many of the teachers may have been relatively inexperienced. Furthermore, South African education is experiencing problems in terms of inadequate teacher qualifications and low provision of educational aids (Howie, 2001). In 2001, only 1% of black matriculants wrote the Higher Grade mathematics examination.

The Minister of Arts, Culture Science and Technology, Dr. Ben Ngubane (2000), stated that Government does take science and mathematics seriously, and is committed to confronting the evidence derived from TIMSS-R and its implications. He stated that in South Africa there are too few researchers (0.72 per 1000 members of each profession), and this is clearly the result of low intakes in science and engineering faculties at universities and technikons.

President Thabo Mbeki (2000 and 2001) emphasised the centrality of mathematics and science as part of human resource development and stated:

Special attention will need to be given to compelling evidence that the country (South Africa) has a critical shortage of mathematics, science and language teachers, and to the demands of the new information and communication technologies. (National Strategy for Mathematics, Science and Technology Education in General and Further Education and Training, 2001: 2).

In the National Strategy for Mathematics, Science and Technology Education in General and Further Education and Training which was published by the Department of Education (2001:12), it is stated that the low level of output in

science and mathematics has a direct impact on the system to produce qualified science and mathematics educators. It is reported that only 50% of mathematics and 42% of science teachers were professionally qualified in their fields. It is also reported that more than a third of mathematics, 45% of general science and 40% of physical science teachers had less than two years of classroom teaching experience.

### **2.10. Gender issues in science learning and achievement**

Keeves and Kotte (1996) reviewed sex differences in mean science achievement scores in ten countries. They summarized their patterns of findings not only in terms of age groups from 10 years to 18 years; but also within the major science fields of biology, chemistry, and physics. They concluded that clear differences in science achievement occurred between 10-year-old boys and 10-year-old girls; that these differences widened during the years of high school; and that they were greater in the physical sciences than in biology.

The TIMSS-R (2001:14) results revealed that there were no significant differences South African between boys and girls on the overall achievements. However, significant differences were observed in two content areas; Earth Sciences and Physics. On physics, boys achieved 5% higher than girls. →

✓ In Nigeria, Erinoshio (1994) recorded that some differences occurred between boys and girls in their performances in physics, chemistry and biology. For example, in physics, 58.6% of girls passed in contrast with 55.4% of boys. In chemistry, 50.5% of boys and 48.1% of girls passed. In biology, 64.2% and 56.7% of boys and girls respectively passed.

With few exceptions, boys have been found to outperform girls in science achievement measures (Walberg, 1967; Fleming and Malone, 1983; Erickson

and Erickson, 1984; Howie and Doody, 1989; Levin, Sabar and Libman, 1991; and Young and Fraser, 1994).

Keeves (1992) compared the results of the first and second IEA studies and suggested that, for a few countries, female students outperformed male students, particularly in the physical sciences, narrowing the gender differences in science achievement.

Many studies have focused on attempting to explain the sex-related differences that have been found in science achievement. The attempts to explain the gender differences have centered on two opposing theoretical perspectives: biological causes and sociological causes of sex-related differences in science achievement. The sociological causes appear to have wider acceptance in the educational community.

Among Nigerian chemistry students, gender differences were attributed to social attitudes, values, interests, aspirations and other cultural practices like socialization (Adigwe, 1992).

Theorists favoring sociological explanations for gender differences in science achievement have frequently focused on the classroom process as a possible key to understanding the origins of gender differences in science achievement (Hacker, 1992).

They suggested that gender differences in science achievement arose from differences in some factors associated with everyday out-of-school activities and classroom experiences (Kahle and Lakes, 1983; Johnson and Murphy, 1984; Johnson, 1986; Hoffman, 1987; Haggerty, 1987).

Weinburgh (1995) reviewed the literature between 1970 and 1991 to analyze gender differences in student attitudes towards science. Her findings suggested

that males might have shown more positive attitudes than females toward science in the parallel differences in their science achievement.

### **2.11. The intelligence theory of Franus, and scientific thought systems**

Franus (1992) identified five subsystems of thinking that will be used in this study to examine the practical task items. The practical tasks' perceived relevance to the subsystems of thinking will be discussed in Chapters 4 and 5. These subsystems of thinking are presented in Table 2.2 below.

One of the purposes of the present investigation will be to gauge the extent to which his cognitive and technical subsystems of thinking might or might not accurately reflect the intellectual processes which occur during basic practical activities in science, based on the evidence gathered during the current study.



Table 2.2 Five subsystems of thinking after Franus (1992: 163)

	<b>Cognitive</b>	<b>Technical</b>	<b>Artistic</b>	<b>Musical</b>	<b>Literary</b>
<b>Direction</b>	Cognition of the objective reality	Production of material objects which have utilitarian value	Painting, graphic art, sculpture	Instrumental or vocal music	The ranges of belles lettres.
<b>Leading Idea</b>	Development of a system of knowledge	The improvement of living conditions	Development of aesthetic culture	Development of musical culture	the development of humanity's general culture
<b>Kind of creative product</b>	Scientific statements and theories	Construction of material objects and the refinement of technological processes	Picture, sculpture, architecture, decoration	Musical compositions	Prose, poetry
<b>Immediate aim</b>	Cognition of truth	Refinement to create the most advantageous, utilitarian form of a product	Expression of an idea using an artistic resource and the current concept of beauty	Creation of acoustic beauty and power of expression in sound	Creation of a beautiful product through the best form to express the ideas.
<b>Function of product</b>	Solution to curiosity and interest, as well as the need for knowledge in order to use it in practice	Facilitation of life and work	Excitation of aesthetic emotions and feelings.	Excitation aesthetic feelings	The development of a world-outlook, imagination, feelings and attitudes in readers.
<b>Dominant carrier of information</b>	Word, verbal descriptions, enriched by patterns, symbols and drawings	Technical drawing, enriched by verbal descriptions, symbols and patterns	The composition of forms and colours	Notes, music record	Verbal language
<b>Material substance of action</b>	The environment world, nature, people, social organisations	Raw materials and semi-manufactured goods	Special artistic accessories	Sounds	Written and spoken words.
<b>Dominant substance of thinking</b>	Imaginative-conceptual categories, scientific laws, theories, hypotheses, empirical data	Technical notions (of materials, norms, operations), technical images (spatial, kinetic, constructive, operative), scientific rules	Images of forms and colours, images of compositions, spatial images	Acoustic images of sounds, melody mode, rhythm, timbre, chords, percussion consonance, dissonance	Words and imaginative-conceptual constructs from all areas of life.
<b>Thinking rigorous</b>	Strictness which is dependent upon problems	Mathematical precision	The discretionary aspects of choice of composition, and means of expression	Discretion in the style of composition and instrumentation	Deep, humanistic and generalised.
<b>Scale of freedom of creative action</b>	Limited by level of knowledge available on the topic and resources available for research	Limited by scientific cognition of natural laws, the state of technology, and the possibility of carrying it out in practice (within economic, cultural, social restraints).	Unlimited	Unlimited	Unlimited
<b>Classification Symbols</b>	F cog	F tech	F art	F mus	F lit

### 2.12. The intelligence theory of Gardner, and scientific thought systems

Gardner (1983) advocated his theory of "*Multiple Intelligence*" challenging a single numerical IQ score. According to Gardner, components of intelligence can be identified separately, and some people develop some types of intelligences more than the other types of intelligences. Gardner conceptualized the human potential and mapped out the human abilities into seven intelligences as follows:

1. **Linguistic Intelligence.** Linguistic intelligence can be developed through a variety of ways such as brainstorming for ideas about a science concept and recording them, using a task or diagram to explore students' understandings, dialoging with the teacher, telling stories of scientists, debating scientific issues, writing research papers, carrying out scientific discussions, and communicating science using proper vocabulary.

Especially in the pilot stages of this research, *Linguistic Intelligence* will be involved when the participants are asked to discuss and critique the practical items among each other and to comment on the items either verbally or in writing. The participants will be required to communicate science thorough appropriate vocabulary. Therefore, if this kind of practice is utilized in a science class, it may contribute to the development of the learners' *Linguistic Intelligence*.

2. **Logical-Mathematical Intelligence.** Those students who exhibit logical-mathematical intelligence show interest in new developments in science, conduct "what if" experiments, give rational explanations for events, think on a more abstract and conceptual level and ask questions about how things work. They also like to conceptualize, think critically, measure, categorize, analyze and quantify. They enjoy engaging Socratic questioning. In this method the teacher does not talk at students; instead, he/she dialogues with

students to find out the students' opinions and beliefs about science concepts.

This kind of intelligence will be involved in physics practical items 1, 2, 3, 4, 5, 7, 8 and 9, to be explained in chapter 3, when the current practical items may be used to develop *Logical-Mathematical Intelligence* of science learners. With some revision and amendment of practical tasks this may be achieved more effectively. For example the learners may be given a related problem and they may be asked to work out the procedure and do the actual investigation (e.g. current at different points of a series circuit, etc.).

**3. Spatial Intelligence.** *Spatial Intelligence* involves pictures and images in one's mind or in the external world. The three dimensional structure of an atom may be an example for the pictures in one's mind.

This intelligence will be involved in items 4, 5 and 6. In these items the participants will have to imagine the powers of the bulbs that are used at homes, and the power of the bulb of a refrigerator, etc.

**4. Bodily-Kinesthetic Intelligence.** *Bodily-Kinesthetic Intelligence* involves hands-on experiments, and whole body movement. Hands-on science is an active process when the senses are brought into action. However it involves thinking as well.

In all of the practical items, the participants will be required to handle and work with different types of apparatus. Therefore this kind of intelligence may have a strong relation to the practical test items used in this study. Again, the practical items may be used in different formats in order to achieve better outcomes depending on the context and the aim the exercise, (e.g. to let the students connect the ammeter; to let them connect the resistors to get different overall

resistances; to ask students to make different connections of cells; to ask students to obtain a real image of the window and to show it to the class, etc.)

5. **Musical Intelligence.** *Musical Intelligence* may be developed in science by encouraging the students to write poems or songs by using scientific concepts; or by investigating the properties of sound using different musical instruments.
6. **Interpersonal Intelligence.** Learning occurs through observing, listening and speaking. Thus it is a social phenomenon. Interpersonal relationships can be developed when the group members freely share their ideas about science concepts. Thus a science class may serve as a context in which to develop interpersonal communication skills.

As in the case of *Linguistic Intelligence*, *Interpersonal Intelligence* will also be involved, especially during the pilot stages of this research.

7. **Intrapersonal Intelligence.** Working together is critical in science but so is the work of the individual scientist. A scientist may produce a solution to an issue that has not been recognized by anybody yet. In a science class, allowing the students to explore their own ideas about a natural phenomenon may develop the intrapersonal skills of the students. In this way the students may be involved in self-assessment.

In order to allow the development of *Intrapersonal Intelligence*, the students in science class may be allowed to perform these practical tasks and may be required to compare their responses with the expected ones. In this way the students will be able to assess themselves as well, which is one of the points that is emphasized by Outcomes-Based Education.

In this preliminary theoretical analysis of the items according to the Multiple Intelligence theory of Gardner, the intelligences numbered 2, 3, 4, and 7 appear to be strongly related to the current study. The intelligences numbered 1 and 6 also appear to be involved in making the amendments and revisions of the format of these practical test items.

### **2.13. Chapter summary**

This chapter has presented and discussed a review of relevant literature in twelve sections. It examined the issues around science process skills which are playing an important role in the latest Revised National Curriculum Statement Draft and their analysis and assessment. The chapter discussed the notions of scientific and technological literacy and gave a summary of the studies on these fields. Research studies conducted in specific topic areas of physics were also presented, together with methods of teaching science in everyday contexts. Other issues discussed in this chapter included assessment practices in science teaching, the importance of teacher training, and gender issues in learning and teaching science. The theoretical inputs of various writers such as Solomon (1998), Gardner (1983), Franus (1992) and White (1998) have been introduced.

## CHAPTER 3

### RESEARCH METHODOLOGY

In this chapter the sample groups of respondents who took part in this research, the format in which the research has been conducted, the practical test items used to collect the data, the nature of the data, and the methodology for processing and validating this data are described, explained and discussed. Fourteen derived null hypothesis are presented for subsequent testing in Chapter 4. Ten core items containing 17 individual practical tasks are selected for inclusion in the final version of the compact programme after extensive field-testing and pruning. Their selection is justified in terms of the literature-derived criteria adopted in chapter 1, section 1.2, and in terms of their satisfactory item analysis parameters.

#### 3.1 The sample groups of respondents

Twenty-nine geographically convenient and randomly available samples were involved in this study – eleven in phase 1, and 17 in phase 2. Testing occurred in educational institutions ranging from the most impoverished to the most affluent, and the total number of respondents exceeded 300. Participants supplying feedback and suggestions included primary, secondary and tertiary level students, and also included science educators and academics attending national conferences at the University of Stellenbosch and the Peninsula Technikon, and participating in an international conference at the University of Port Elizabeth during the period of 1999 – 2001.

The size, nature and characteristics of the sample groups were as follows:

**Sample 1:** Four general and physical science teachers-in-training at the University of Cape Town who piloted an initial pool of 33 possible items.

**Sample 2:** Five grade eleven physical science students at St. George's Grammar School who critiqued the same batch of 33 practical items.

**Sample 3:** Eight science and technology teachers and lecturers at University of the Western Cape who critiqued 12 more refined versions of the items.

**Sample 4:** 14 grades 10-12 Xhosa speaking physical science students from a historically disadvantaged physical science class at Oscar Mpeta High School who wrote suggestions and comments on 18 of the items.

**Sample 5:** 16 grades 5-7 science students at Lanner House Primary School, Worcester who participated in the trial of 21 of the more basic practical items and commented on them from their point of view.

**Sample 6:** Seven science and technology education academics attending a Southern African Association for Research and Development in Higher Education (SAARDHE) conference at the Peninsula Technikon in June 1999. This sample group of participants critiqued, validated and classified the items according to the theories explained in Chapter 4.

**Sample 7:** 24 grade 8-11 students, from different schools in the Western Cape, attending the annual Science EXPO held in the Education Building, University of Cape Town who trialled eight of the practical items in optics.

**Sample 8:** Six Afrikaans speaking bilingual primary science and technology teachers-in-training at the University of Stellenbosch who critiqued, responded to and commented on different aspects of 34 trialled practical items.

**Sample 9:** Eleven primary science and technology teachers-in-training at the University of Cape Town who evaluated and commented on the practical items.

**Sample 10:** Four science and technology education lecturers at the University of Cape Town who critiqued and classified the practical items according to different theoretical frameworks.

**Sample 11:** Nine science and technology education academics attending a Southern African Association for Research in Mathematics and Science Education conference held at University of Port Elizabeth in January 2000 who critiqued, validated and discussed the practical items in terms of their relevance to different learning theories of science.

**Sample 12:** 29 Grade 8 learners at Camps Bay High School who responded to the final programme containing ten core practical items, (comprising 17

individual tasks), and who also commented on the nature, value and difficulty of the items.

**Sample 13:** 17 Grade 10 biology only students at Camps Bay High School who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

**Sample 14:** 18 Grade 11 biology only students at Camps Bay High School who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

**Sample 15:** 15 Grade 12 biology only students at Camps Bay High School who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

**Sample 16:** 15 Grade 12 science students at Camps Bay High School who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

**Sample 17:** 28 Grade 10 Xhosa-speaking physical science students at Masiyile High School who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

**Sample 18:** 26 Grade 11 Xhosa-speaking physical science students at Masiyile High School who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

**Sample 19:** 32 Grade 12 Xhosa-speaking physical science students at Masiyile High School who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

**Sample 20:** 19 Grade 10 physical science students at Livingstone High School who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

**Sample 21:** 29 Grade 12 physical science students at Livingstone High School who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.



**Sample 22:** Nine Science teachers-in-training at the University of Cape Town who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

**Sample 23:** 23 Primary school teachers-in-training, receiving science education classes who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

**Sample 24:** 19 Grade 9 general science students at Star International High School who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

**Sample 25:** 10 Grade 10 physical science students at Star International High School who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

**Sample 26:** 7 Grade 10 biology students at Star International High School who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

**Sample 27:** 19 Grade 11 male learners at Islamia High School who responded to the final ten of core practical items, and who commented on the nature, value and difficulty of the items.

**Sample 28:** 19 Grade 11 female learners at Islamia High School who responded to the final core of ten practical items, and who commented on the nature, value and difficulty of the items.

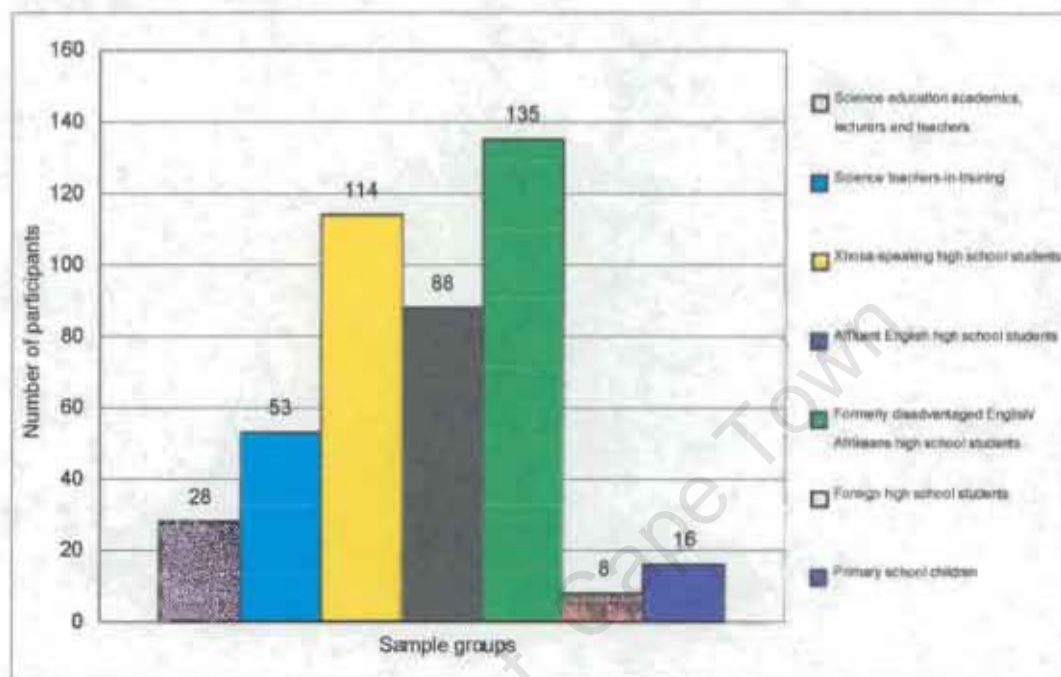
## **3.2 Research Methodology**

### **3.2.1 Survey research method**

Initially, willing and available sample groups of participants were randomly selected to collect data for the research. This involved choosing or inviting respondents from geographically most convenient institutions within a radius of 100 kilometers. After this, more purposive sampling was implemented to

include participants at all levels of socio-economic status and educational background, as depicted in Illustration 3.1.

Illustration 3.1 The nature of the 442 participants in the research study (phase 1 and phase 2), grouped according to educational status



### 3.2.2 Administration of the practical test items

In this study, instead of engaging the more traditional paper-and-pencil type of assessment items, a compact programme of core practical assessment items in high school was developed and used to collect the data. Laugksch and Spargo (1996:127), who developed paper-and-pencil types of test items to measure scientific literacy, also stated that it was no longer fashionable to advocate the use of paper-and-pencil types of assessment, and therefore new assessment strategies should be used.

In implementing these new, untutored practical activities, actual items of apparatus were physically present, together with written instructions, and the participants were invited to attempt to employ process skills to answer each question by handling, exploring and examining these items of apparatus. Each

item's station was presented on a mounted display with a black paper background, as shown in the photographs in Figures 3.10 to 3.10 described in the next section.

Usually a large room was required for the administration of these items, because each item had to be presented separately, and each display occupied an area of roughly half a square meter. Because the participants also required space to work with each item, a fairly large area was sought for the administration of the test, such as a school hall in some instances.

### 3.2.3 Initial and final selection of the core items and practical activities

The practical test items were selected from the basic content of the chapters of standard South African school science school textbooks such as Brink and Jones (2000) Physical Science Grades 10-12; van Zyl, Craul, Meyer, Muller, Spies, and van Harte (1999), Physical Science Grade 11-12, Study and Master. The optics items, for example were selected because they appear in the Grade 9 and 10 physical science syllabi. However optics is not involved in the final year (matriculation) syllabus, so some senior classroom educators do not necessarily cover the chapters on optics with senior classes. Nevertheless, the practical items included in this study are usually covered during school science teaching at different grade levels, at different levels of complexity and difficulty.

Initially, 33 practical items and activities were developed. The wording, apparatus and presentation format of these items underwent numerous modifications through various pilot trials, as reported below in section 3.4.

In phase 1, sample groups, numbers 1 to 11 listed above, were involved in these pilot trials. The items were progressively modified in their content and wording, according to the received responses and comments. In phase 2, for the large data collection, ultimately only ten of these 33 items were chosen for the mass

data collection with the subsequent groups of participants, namely, samples groups numbers 12 to 28. The final core of ten basic items, emphasizing process skills, comprised a total of 17 individual activities, and formed the compact version of the practical programme adopted for phase 2 mass testing. In accordance with the selection criteria adopted in chapter 1 (section 1.2), Table 3.1 records how well each practical item matches the 2001 science curriculum criteria, as agreed upon by consensus of a panel of four experienced science educators.

Table 3.1 The Revised National Curriculum Statement Draft (2001) process skills tested by the compact programme of selected core apparatus-based practical items in basic physical science

ITEM	Observing and comparing	Measuring and estimating	Recording information	Sorting and classifying	Interpreting information	Predicting what will happen if something changes	Hypothesizing	Using models and theories	Raising questions about a situation	Planning investigations	Doing the investigation	Communicating science information	Design, make and improve a device or system to solve a particular problem
1- Measuring cylinder	✓	✓	✓				✓			✓	✓	✓	
2- Shoes	✓	✓						✓					
3- Magnets	✓				✓	✓	✓	✓		✓	✓	✓	
4- Light globes comparison	✓			✓	✓		✓					✓	
5- Light globe estimation	✓	✓	✓		✓	✓			✓			✓	
6- Cell combinations	✓			✓	✓			✓	✓				
7- Resistance calculation	✓		✓					✓				✓	
8- Current reading and estimation	✓	✓				✓	✓	✓				✓	
9- Matching mirror types	✓			✓								✓	
10- Image by lenses	✓				✓		✓	✓		✓	✓		

Table 3.2 also records how well the compact practical programme as a whole, in its final form, meets the criteria advocated by the National Draft Revised

Curriculum Statement (2001:4;7;10;14-16), in the consensus judgment of six experienced teachers of physical science – three Afrikaans-English bilingual, one Turkish-English bilingual, and two whose prime language is English. The teachers/judges rated the relevance of the practical tasks to the process skills on a scale of 0 (not relevant) to 3 (highly relevant).

University of Cape Town

Table 3.2 The consensus views of six experienced teachers of school science on how well the compact programme, as a whole, meets the criteria advocated by the 2001 Revised National Curriculum Statement Draft

Degree of relevance (out of 3)	Criteria
3	Learner-centeredness
3	Activity-based
2	Promotes learners' effective use of visual, mathematical and language skills to communicate
1	Promotes the use of creative and/or critical thinking skills to identify and solve problems
1	Enables learners to organise and manage activities responsibly and effectively
1	Promotes the collection, analysis, organisation and critical evaluation of information by learners
1	Enables learners to use science and technology effectively, showing responsibility to the environments and health of others
1	Enables the learners to understand that the world is a set of related systems
2	Enables learners to make sense of the world
3	Durable
2	Evidence-based
L3,12	Logical and intuitive
3	Enables prediction, verification and repetition
0	Enables validation through peer view
1	Encourages science as a social process
0	Involves an open contest of ideas
3	Promotes the application of scientific knowledge and understanding
2	Fosters an appreciation of the relationships and responsibilities between science and society
3	Requires careful observation
1	Encourages the search for pattern
2	Promotes an understanding of cause and effect
1	Answers questions about the nature of the world
1	Prepares learners for economic activity and self-expression
3	Lays the basis for further studies in science
3	Promotes understanding of science as a human activity
0	Promotes an understanding of the history of science
0	Promotes an understanding of the relationship between science and other Learning Areas
0	Promotes an understanding of the contribution of science to social justice and societal development
0	Promotes an understanding of responsibility to ourselves, society and the environment
0	Promotes and understanding of the consequences that involves ethical issues
1	Acknowledges the existence of 'alternative ideas' of the world by children and adults, which they bring to the world of classroom
3	Encourages girls to participate in the science activities.
0	Is open to new theories and knowledge
3	Is culture-fair

The criteria for test item construction set out by Ebel (1972) and by Marshall and Hales (1971) require measurements of the reliability, difficulty, discrimination and specificity of each particular activity task, in order to justify



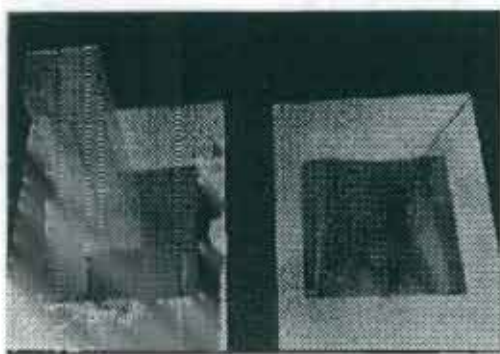
or support the inclusion of each item in the final compact programme of practical work. However, because the relevant coefficients and indices would be better derived from larger scale testing, rather than from pilot trial results, these measured criteria advocated by Ebel and by Marshall and Hales will be calculated and presented in Chapter 4, as part of the results of the investigation. At that point stronger evidence will be available (such as Cronbach alpha coefficients) with which to justify the final selection of the ten core practical items for the compact version of the experimental programme.

Other reasons for limiting the content of the compact programme, and for selecting these particular ten core items on which to focus were : a) in the pilot trials the particular activities produced a wide range of scores; b) since the administration of the test had to occur during the restricted normal work programmes of the various institutions visited, only a limited period of time could be allocated for the administration of items and for the data collection with each group of respondents; c) the feasibility of attempting to manage the processing of a large amount of qualitative data obtained from more than 300 respondents suggested that the number of included activities be pruned; and d) these particular items emphasized process skills.

The presentation, format and wording of these ten core items also underwent a final revision after in-depth discussion with a panel of eight experienced lecturers and science educators, some of whom were involved in earlier stages of the research (sample 3).

The ten core items (comprising 17 individual tasks) finally selected for mass testing in phase 2, are presented in Figures 3.1 to 3.10 below, together with photographs of the apparatus used. Examples from the remainder of the available pool of 33 exploratory items are attached and depicted in Appendix 2.

### Item 1



You are given a measuring cylinder and a solid object. Measure the volume of the object by using the measuring cylinder you have. Write down the value you found on the answer sheet.

Figure 3.1. A measuring cylinder and a solid object.

### Item 2



Examine the three shoes. Choose the one that applies the most pressure on the floor when the same person wears it.

Figure 3.2. A formal shoe, a soccer boot and a sneaker.

### Item 3



Look at the magnets and the compass. Use the compass to identify the *North Pole* of each magnet.

Figure 3.3. A compass and three magnets with different shapes.



#### Item 4



Examine the two light globes (60W and 100W).

- a-Indicate the one which will be cheaper to use when switched on (i.e., which will result in a lower electricity bill).
- b-Indicate the one which will glow brighter than the other when switched on.

Figure 3.4. Two light globes: 100 watt and 60 watt.

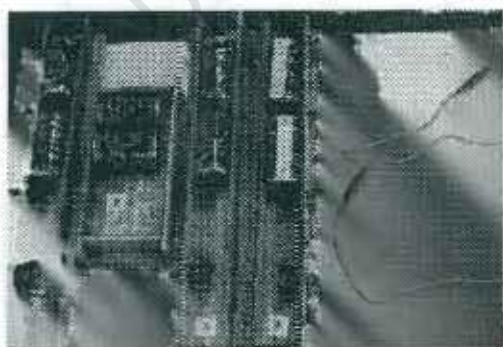
#### Item 5



Read the information on the light globe (3.8V 0.3A). If the light globe has a power of 1 watt ( $3.8 \times 0.3 \approx 1 \text{ Watt}$ ), approximately how many of these light globes would give the same brightness as the light globe in your refrigerator? (You can think of the light bulb in your room and the size of your room, and compare them with a refrigerator).

Figure 3.5. A tiny light globe and an objective eyepiece to use while reading the information on the light globe.

#### Item 6



Examine the four different arrangements of cells (plus to minus, minus to minus, plus to plus etc.) and the bulb. Indicate the one of the four combinations that will allow the bulb to glow for the longest period when connected to the bulb.

Figure 3.6. Four different arrangements of cells (+ to -, - to -, + to + and two cells in parallel) and a light bulb with two wires.

### Item 7



You are given a circuit that involves three resistances each of  $10\ \Omega$  and the cells. Look at the circuit carefully, and study the way the resistors are connected (series, parallel etc.). Work out the overall (total) resistance of the circuit. You can check your answer by means of the reading you see on the ammeter.

Figure 3.7. A circuit involving two resistors in parallel and a third one in series with them; they are altogether connected to two cells.

### Item 8



Look at the circuit given

- Indicate the direction of the conventional current going through the circuit (Away from the + pole of the cells or Towards the + pole of the cells).
- Read the value of the current at the ammeter which is going through point A.
- Guess how much current goes through point B.

Figure 3.8. A circuit that involves two cells in series with two bulbs and an ammeter connected to the circuit at point A.

### Item 9



You are provided with mirrors labeled 1, 2 and 3. Examine them and match the numbers to the types of concave, convex and plane on the answer sheet.

Figure 3.9. A plane, a concave and a convex mirror.

**Item 10**

Look at the double concave lens and double convex lens. By observation, indicate the lens that can give you a real image of the window.

Figure 3.10. A double concave and a double convex lens.

### 3.3 Data collection sheets

#### 3.3.1 The quantitative data collection

A special answer sheet, reproduced in Figure 3.11, was developed for the collection of the quantitative data. Half of the space on this sheet was allocated for the answers to the practical test items, and the other half was assigned for collecting data on the past experiences and the attributes of participants, such as their familiarity with the apparatus used.

In the first half of this answer sheet, a space was provided for the participants to write down their responses to each task. Depending on the types of responses expected from the participants, the format of these spaces varied. In questions where the participants were required to make measurements (e.g. to record the volume of a piece of stone) or read a measuring instrument (e.g. an ammeter), blank spaces were provided so that the participants could write their answers (to items 1, 6, 7, 8b and 8c). For the other tasks the participants were required to examine the apparatus and to tick the relevant boxes on the answer sheets (items 2, 3, 4, 5, 8a, 9 and 10).

On the second half of the page a list of apparatus used in the questions was provided in table form. The participants were asked to indicate whether or not

they had handled these objects at home, at school or both. The participants were required to tick the relevant options for each item of apparatus on this page, i.e. there were three boxes for each item of apparatus labeled “home”, “school” and “never”.

For the purpose of processing the data collected on this part of the answer sheet, the terms “*home familiarity*”, “*school familiarity*” and “*overall familiarity*” were used to classify the participants’ backgrounds according to their previous experience with the apparatus. For the participants, “*home familiarity*” meant that the participant had handled a particular item of apparatus at home; “*school familiarity*” meant that the participant had handled the apparatus at school; and the “*overall familiarity*” meant that the participant had handled the apparatus both at home and at school.

Excluding the pilot trials, a substantial amount of quantitative data was subsequently collected in phase 2, on the now final and stabilized programme, using 340 participants in Cape Town during 2001 in 16 sessions. The duration of each session varied, depending on the size of the group. Because all participants were required to answer the questions individually, only ten participants at a time were allowed to work their way through the programme of ten core activities. No person-to-person discussion was permitted during these sessions. Each person spent an average of 15-20 minutes on the ten tasks in phase 2.

Figure 3.11 Answer Sheet

Name		Age		Grade		Home language		Gender	Male / Female	
						School/Institution				

Item	Response									
1	The volume of the object is (add the unit)									
2	<input type="checkbox"/> Shoe <input type="checkbox"/> Soccer boot <input type="checkbox"/> Sneaker									
3	<table border="1" style="display: inline-table; vertical-align: middle;"> <tr> <td style="width: 100px;">Magnet A-</td> <td style="width: 30px;">1</td> <td style="width: 30px;">2</td> </tr> <tr> <td>Magnet B-</td> <td>1</td> <td>2</td> </tr> <tr> <td>Magnet C-</td> <td>1</td> <td>2</td> </tr> </table> Tick the north pole of each magnet	Magnet A-	1	2	Magnet B-	1	2	Magnet C-	1	2
Magnet A-	1	2								
Magnet B-	1	2								
Magnet C-	1	2								
4	a- <input type="checkbox"/> 60 W <input type="checkbox"/> 100 W b- <input type="checkbox"/> 60 W <input type="checkbox"/> 100 W									
5	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4									
6	The number of the bulbs is .....									
7										
8	a- <input type="checkbox"/> Away from the + terminal of the cells    b- <input type="checkbox"/> Towards the + terminal of the cells    c-									
9	<input type="checkbox"/> Concave <input type="checkbox"/> Plane <input type="checkbox"/> Convex									
10	<input type="checkbox"/> Concave <input type="checkbox"/> Convex									

Indicate which apparatus you have handled before this test	At home	At school	Never
Measuring cylinder			
Magnets			
Compass			
Bulbs			
Torch bulb			
Cells			
Resistors			
Ammeter			
Concave mirror			
Convex mirror			
Plane mirror			
Lenses / magnifying glass			



### 3.3.2 The qualitative data collection

The qualitative data was also collected by means of an open-ended question presented on a separate page (Figure 3.12) and attached to the respondent's answer sheet. After the participants had completed the practical activity programme, they were asked to comment on their experiences with the items. The respondents reflected on individual tasks as well as on the compact programme as a whole. They were also asked to offer their opinions on the nature of the work, and on having this kind of practice in their classrooms.

The studies were conducted by the researcher, and the participants were observed while they were proceeding through the practical activities. During some sessions of the pilot studies the conversations of participants were also recorded by an audio recorder. Samples of the audio-captured data appear in Appendix 3.

**Comments:**

**You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in lessons? Should it be left out of classroom practice?**

University of Cape Town

**Figure 3.12. The comment sheet**

### **3.4 Pilot trial refinements during phase 1**

Pilot studies in phase 1 were conducted with conveniently available random samples on eleven different occasions; for example, during visits to schools, on schools' science days, at science expositions, during seminars, at science and technology education conferences etc., with diverse groups of participants. As mentioned in section 3.1, among these participants, were primary, secondary and tertiary level students, teachers in training, science education academics and science educators. Altogether, more than 400 written comments and suggestions were received during the eleven pilot trials. Examples and summaries of these comments are included in Chapters 4 and 5 and are reproduced as photocopies in Appendix 4.

#### **Pilot trial no. 1**

In the first pilot trial the science teachers-in-training critiqued the items in great detail for 60 minutes. They showed that some of the instructions for the tasks were not clearly worded or they contained faulty apparatus. According to the respondents, six of the items required re-wording, and for four items the working of the apparatus itself needed to be checked. Some examples of the re-wording appear in detail in Appendix 5:

#### **Pilot trial no. 2**

This detailed critique, using five intrinsically motivated grade 12 physical science students at a private co-educational grammar school, lasted for 1.5 hours. From the point of view of the development of the materials themselves, the outcome of the second pilot study was that the apparatus of two items (numbered 7 and 11) of the 33 trialled items was modified or amended. Otherwise all the other materials and activities received a high degree of approval and endorsement by the five students.



**Pilot trial no. 3**

With experienced science and technology educators and lecturers at the University of the Western Cape, the aim was not to attempt to derive the physics answers from the participating attendants. The purpose of the practical evaluation was to obtain a consensus validation of the literary expression of the re-worded items, one by one, and to gather suggestions for improving the acceptability of the whole programme. Comments raised by the attendants during the discussion session are discussed in detail in the next chapter.

**Pilot trial no.4**

The fourth evaluation of the materials, that had already been modified three times, occurred for 45 minutes with English second language (ESL) high school physical science students whose primary language is Xhosa.

As a result of the students' responses and comments and suggestions, wordings of some of the practical items underwent another revision. For example, the initial wording of item 3 was, "What is the smallest weight that this scale can measure?" It was re-worded as, "What fraction of a newton can this scale measure?" Initially Item 9 asked the participants to identify a magnet with opposite polarity, but the participants had difficulty in understanding the instruction. Therefore it was revised, and it subsequently asked the participants to identify the north pole of the magnet.

**Pilot trial no. 5**

This study, lasting two hours, was conducted using only 21 elementary items and activities with primary school children aged 10-13 years. It was surmised that even some members of the general public might also have attained only a basic everyday literacy in science and technology at a primary school level, so feedback was sought from younger children as well. Therefore only the simple tasks were used. The first aim of this study was to record what kind of reaction the primary school pupils would give to such an exploratory activity, while

introducing them to a little practical work as part of their normal elementary science and technology lessons. The primary school students, who were in grades 5-7, said they enjoyed handling the apparatus such as mirrors, lenses, simple circuits, burning the bulbs, etc. This study was conducted during a formally time-tabled, structured science day organised by their school. The verbal and written responses of the children indicated that they valued the experience and learned new science and technology skills and subject content (as indicated in their comments recorded in attached Appendices 3 and 4).

#### **Pilot trial no. 6**

Seven science and technology education academics participated actively in this study during a national higher education conference. The attendants evaluated the practical items in optics by consensus, and they classified the activities successfully according to the themes and categories of Solomon, Lock and OBE which were presented to them on cards of different colors (Appendix 6).

#### **Pilot trial no. 7**

This study was administered during a regionally organized science expo, in which talented school pupils from different schools exhibited their projects and competed with each other, at the University of Cape Town. The volunteer participants, who were science enthusiasts in grades 8-11, evaluated eight items on optics in detail.

#### **Pilot trial no. 8**

The eighth pilot trial was conducted at the University of Stellenbosch with primary science and technology teachers-in-training and academics. Their overall impression on the programme of 33 refined items was strongly encouraging, expressing the wish that it be extended to wider samples and enlarged. The detailed evaluation of the tasks took 45 minutes, and all the

participants urged and requested that the programme be repeated with their other classes of students in the near future.

#### **Pilot trial no. 9**

This pilot trial was administered at the University of Cape Town, with eleven primary science and technology teachers-in-training. They evaluated all the items in writing and responded to them, and they also made further small comments on different tasks. It was concluded that the structure, format, working and relevance of each item were now clear and acceptable.

#### **Pilot trial no. 10**

The tenth study involved four science and technology education lecturers at the University of Cape Town. The attendants also classified six of the items according to the presented details of three theories: those of Specific Outcomes, Fransus and Lock on cards of different colours; and they reached consensus.

#### **Pilot trial no. 11**

Nine academics participated in this last pilot trial during an international conference of Southern African researchers in mathematics and science education. They evaluated sample tasks from different topics, and gave further comments on individual items and on the programme in general, as recorded in Appendix 7.

Various participants described the most serious shortcomings of the practical tasks and their materials in the early phases as follows:

- Some of the instructions were ambiguous and misleading,
- Some items of apparatus were not clear,
- The answer sheet was incomplete and not well-prepared,
- During the administration of the test at the early stages the number of participants in one group was too large,

- Some signs and symbols that the students were not familiar with were used without explanation (e.g.  $\Omega$  ), and
- Some items lacked a focus outcome.

This investigation was conducted mostly with science classes. It would be interesting to find out how the students who are not taking up science would react to this kind of activities.

### 3.5 Treatment of the data collected

The proposed method of treatment of the quantitative and qualitative raw data is described in this section.

#### 3.5.1 Treatment of the quantitative data

The marks allocated to each task varied from item to item. The whole test totalled 25 scale points. For the tasks in which the participants were required to write down the result of a measurement, marks were scored for stating the *units* of measurements, and for the *way of expressing* the units (e.g. when writing “cm<sup>3</sup>”, the location or position of the number “3” in expressing unit of volume also counted for marks).

The items were scored as follows: -

**Item 1.** The task was worth of 3 scale points: 1 mark was allocated for the correct numerical value of the volume, 1 mark for the unit and 1 mark for the notation of expressing “cube”.

**Item 2.** The task counted 1 mark.

**Item 3.** The task counted 3 marks: 1 mark was awarded for the correct identification of each magnet.

**Item 4.** The task counted 2 marks: 1 mark was allocated for part 'a' and 1 mark for part 'b'.

**Item 5.** The task counted 1 mark.

**Item 6.** The task counted 3 marks. In this question the participants were required to estimate number of tiny bulbs. The evaluation of the responses in this item depended on how close the participant's response was to 15, which was accepted to be the correct answer. 3 marks were awarded if the response was 14-16, 2 marks were awarded if the response was 10-13 or 17-20, and 1 mark was awarded if the response was 5-9 or 21-25. No mark was awarded for the responses that were not between 5 and 25.

**Item 7.** The item counted 2 marks: 1 mark was awarded for the numerical value of the resistance and 1 mark was awarded for the unit.

**Item 8.** The item counted 6 marks: 1 mark was allocated for part 'a'. For parts 'b' and 'c', 1 mark was awarded for the numerical value of the current in each part, 1 mark was awarded for the unit of the current, and 1 mark was awarded if the participant gave the same answer to parts 'b' and 'c'. The reason for this was that current in a series circuit is the same at every point of the circuit. Therefore, if a respondent gave the same value for both parts, even if the value was wrong, 1 mark was awarded.

**Item 9.** The item counted 3 marks: 1 mark was awarded for each mirror identified correctly.

**Item 10.** The item counted 1 mark, awarded for choosing the correct lens.

To prepare the quantitative data for subsequent statistical analysis, the total scores on the test as a whole (25 marks), as well as item by item, will be obtained for various grouping arrangements (such as male/female; English first language/second language; etc.).

The answers collected from the participants will be entered into the computer by the researcher to store for the statistical analysis. Data will be stored by Microsoft Excel, the computer software that enables the user to record data on

spreadsheets. When entering the data into the computer on “the familiarity of the participants with the apparatus used in the practical items”, numerical values will be used to be able to utilise this data for statistical purposes, i.e. 1 point allocated for each degree of familiarity of a participant with a given item of apparatus. If a participant handled a particular piece of apparatus both at home and school he/she will be given 2 points. The data stored in Excel will be then transferred to another software package, Statistica, to perform the statistical analyses.

The proposed method of quantitative analysis will involve calculations of indices of difficulty and discrimination for each item; calculation of means, standard deviations, and alpha coefficients for the total achievement scores of various samples; and use of chi-square and t-tests for comparisons of the participants’ responses; etc.

### **3.5.2 The qualitative data: proposed methods of treatment and analysis**

The responses given by the participants to the open-ended question will be reflected on and summarized. An attempt will be made to develop analytical questions, and to classify the responses using emerging categories, themes, patterns, perspectives, relationships and indicators, and to identify the conceptual and substantive issues embedded in the responses.

The suggestions made by the participants, during both the pilot studies and the mass study, will be analysed. Possible conclusions will be drawn and recommendations made. The observed interactions of the participants, both with the items and among each other (during pilot studies) will also be reported.

## **3.6 Null Hypotheses**

The following 14 null hypotheses will be tested in phase 2: -

***Null hypothesis 1a:*** Overall achievement of 308 secondary and 32 tertiary level students on the compact programme of 17 activities.

Ho1a. There will be no significant difference between the total achievement scores of the secondary students and the tertiary level students.

***Null hypothesis 1b:*** Achievements of secondary and tertiary level students on individual task items.

Ho1b. There will be no significant differences between the achievement scores of the high school students and the tertiary level students on each one of the 17 individual tasks comprising the ten basic items.

***Null hypothesis 2a:*** Overall achievement scores of the 157 males and 172 females.

Ho2a. There will be no significant difference between the total achievement scores of the 157 male and 172 female participants.

***Null hypothesis 2b:*** Achievement scores of males and females on individual items.

Ho2b. There will be no significant differences between the achievement scores of the males and females on each one of the 17 individual tasks comprising the ten items.

***Null hypothesis 3:*** Overall achievement scores of students from different grades.

Ho3. There will be no significant differences between the total achievement scores of the high school students from each different grade level.

***Null hypothesis 4:*** Involvement of particular topics in the matriculation syllabus and the achievements of participants on these items.

Ho4. There will be no significant difference between the high school students' achievement percentages on those items that are involved in the matriculation syllabus and on those items that are not.

*Null hypothesis 5a: Overall achievement scores of participants according to their English proficiency levels.*

Ho5a. There will be no significant difference between the total achievement scores of participants who are English first language speakers and those who are not.

*Null hypothesis 5b: Achievements of participants according to their English proficiency levels on individual tasks.*

Ho5b. There will be no significant differences between the achievement scores of participants who are English first language speakers and those who are not, on each one of the 17 individual task items.

*Null hypothesis 6a: Overall achievement scores of participants and their schools/institutions.*

Ho6a. There will be no significant differences between the total achievement scores of the groups of participants classified according to their schools/institutions

*Null hypothesis 6b: The participants' schools/institutions and their achievement scores on individual tasks.*

Ho6b. There will be no significant differences between the achievement scores of participants from different schools on individual tasks.

*Null hypothesis 7a: Correlation between scores of overall achievement and "home familiarity" scores.*



Ho7a. There will be no significant correlation between the total achievement scores of participants and their scores for total home familiarity with the apparatus.

*Null hypothesis 7b: Correlation between scores of overall achievement and "school familiarity" scores.*

Ho7b. There will be no significant correlation between the total achievement scores of participants and their scores for total school familiarity with the apparatus.

*Null hypothesis 7c: Correlation between scores of overall achievement and "overall familiarity" scores.*

Ho7c. There will be no significant correlation between the total achievement scores of participants and their scores for total overall familiarity with the apparatus.

*Null hypothesis 8: Correlations between participants' achievement scores on individual items and their "extent of familiarity" with the apparatus used in particular items*

Ho8. For individual items, there will be no significant correlation between the achievement scores of participants and their "extent of familiarity" with the apparatus that was used in the particular item.

### 3.7 Chapter summary

This chapter has introduced the samples engaged in the study, the systematic refinement of the research instruments, and the methodology in which the study was conducted. The hypotheses to be tested, and the methods of processing the qualitative and quantitative data have also been explained. Details of the 17 individual tasks finally adopted for use in phase 2 of the investigation have also

been presented, and the selection of these tasks has been justified in terms of the specified criteria adopted in section 1.2 of Chapter 1.

The results and findings of the study will now be presented in Chapter 4.

University of Cape Town

## **CHAPTER 4**

### **PRESENTATION AND ANALYSIS OF RESULTS**

In this chapter, the results and findings are presented in five sections.

Sections A to C report the mass findings obtained for phase 2 of the investigation, when a total of 340 participants from a wide range of backgrounds (samples 12 to 28) were tested over a period of six months on the compact programme of exploratory practical activities in basic physical science. This programme comprises ten core items containing a total of 17 individual performance tasks requiring the demonstration of science process skills.

Section A presents the basic statistical properties and parameters of the compact programme as a whole, as well as item by item, using the raw data obtained from the 340 respondents, in unrefined form. Statistical analyses are then performed on the raw data to detect and possibly discard any clearly defective items or activities. If necessary, a refined or statistically improved form of the performance scores on the compact programme will then be obtained for use in subsequent hypothesis testing.

Section B presents the quantitative findings of the research in which the hypotheses are tested statistically, and the results are analyzed and displayed through various tables and graphs.

Section C sets out the qualitative findings. It analyses, summarizes and reflects on the responses of the 340 participants to the open-ended question (Figure 3.12 The comment sheet). It attempts to develop analytical questions and to classify the responses using emerging themes, categories, patterns, relationships, indicators and perspectives. It also seeks to identify important conceptual and substantive issues embedded in the responses.

Section D reports the results obtained when juries of four to eight experienced professional science educators from two universities attempt to establish the extent to which each one of the 17 individual practical task items is congruent with (i.e. is in harmony with, matches and is relevant to) the theories, criteria and classification schemes of science practical work advocated by Franus (1992), Gardner (1983), White (1988), Solomon (1998), Kapenda et al. (2001), Race (1997), Lock (1990) and OBE (Revised National Curriculum Statement Draft, 2001).

Finally, in section E, the findings recorded in Sections A to D are used to synthesise and present the evidence showing the extent to which the final version of the compact programme of practical activities meets and satisfies the 13 standard criteria for test item construction prescribed by Ebel (1972) and Marshall and Hales (1971), such as efficiency, specificity, fairness, difficulty, directedness and so on.

#### **4.1 Section A: The compact programme: its basic statistical properties and parameters**

Table 4.1 records the means, standard deviations and  $\alpha$ -coefficients for the individual practical tasks obtained with  $n=340$  participants, and also for the test as a whole, i.e.  $\alpha=0.58$ . According to Prof. M. B. Ogunniyi (personal communication, 13<sup>th</sup> October 2000), "The reliability of practical test items is customarily uncertain". When Harlen (1999:139) examined science process skills and their assessment, he pointed out that the validity of the instrument is more important than its reliability. Thus, an alpha-coefficient of 0.58 for this compact programme as a whole is not unsatisfactory. Removal of three activities, namely items 2, 3B and 5, however, would improve the coefficient cronbach alpha to 0.65.

Table 4.1 Parameters and statistical properties of the final ten core items (consisting of 17 individual tasks), comprising the compact programme of apparatus-based practical activities in basic physical science for a combined sample of  $n=340$  test participants in phase 2 of the investigation

Items/activities	n	Mean	SD	Max.	Cronbach alphas	
1. Displacement volume	340	1.82	1.31	3	-	
2. Shoe pressure	340	0.55	0.50	1	-	
3A. Magnet A	340	0.41	0.49	1	0.48	
3B. Magnet B	340	0.52	0.50	1		
3C. Magnet C	340	0.46	0.50	1		
4A. Electricity: light globe cost	340	0.95	0.22	1	0.12	0.50
4B. Electricity: Light globe brightness	340	0.94	0.24	1		
5. Electricity: Refrigerator light	340	0.73	0.93	3	0.61	
6. Electricity: duration	340	0.28	0.45	1		
7. Electricity: resistance	340	0.55	0.67	3		
8A. Electricity: current direction	340	0.68	0.47	1		
8B. Electricity: Ammeter reading	340	0.37	0.63	2		
8C. Electricity: Current estimation	340	0.53	0.83	3		
9A. Light: Concave mirror	340	0.64	0.48	1	0.85	0.67
9B. Light: Convex mirror	340	0.61	0.49	1		
9C. Light: Plane mirror	340	0.79	0.40	1		
10. Light: Lens image	340	0.24	0.43	1	-	
Total score	340	11.06	3.91	25	0.58	

Table 4.2 explains how the Cronbach alpha coefficient for the test as a whole would be altered (marginally) by the removal of individual items. However, since deletion of items 2, 3B and 5 from the compact programme will have only slight effect on the total reliability, all 17 activities will be retained for the next stage of the analysis of the participants' scores. However hypotheses involving the unreliable activities 2, 3B and 5 taken individually, will be treated very cautiously.

Figure 4.1 Distribution of the total scores on the compact programme of 17 practical activities by a sample of  $n=340$  participants (Maximum possible score = 25).

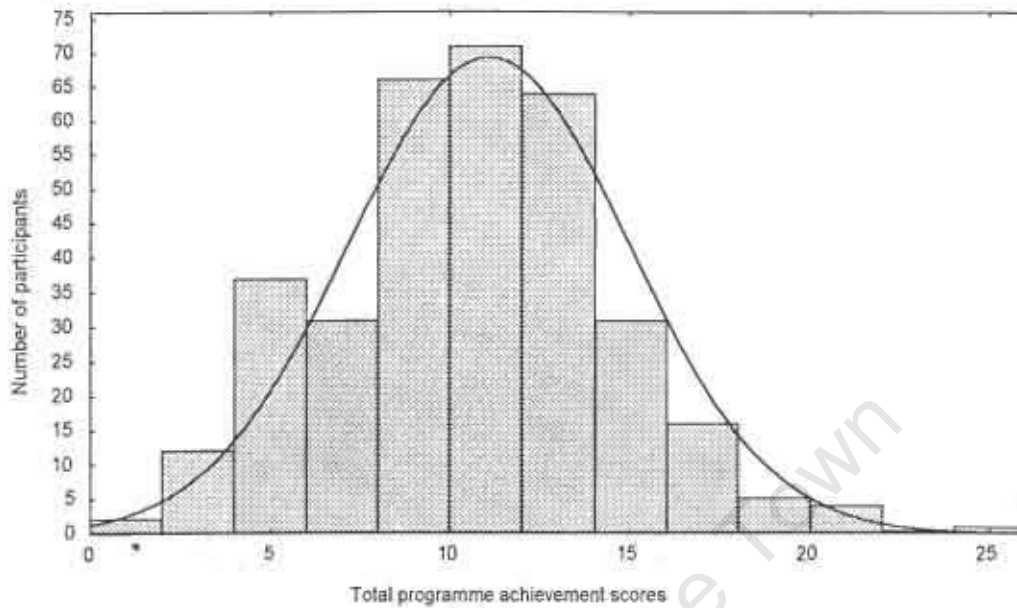


Table 4.2 Theoretical effect of deleting single practical task items on the Cronbach alpha coefficient for the whole compact programme ( $\alpha=0.58$ , whole test)

Items	Item-to-total correlation	Alpha if deleted
1. Displacement volume	0.37	0.53
2. Shoe pressure	-0.11	0.60
3A. Magnet A	0.19	0.56
3B. Magnet B	-0.07	0.60
3C. Magnet C	0.11	0.58
4A. Electricity: light globe cost	0.19	0.57
4B. Electricity: Light globe brightness	0.18	0.57
5. Electricity: Refrigerator light	-0.01	0.62
6. Electricity: duration	0.27	0.55
7. Electricity: resistance	0.40	0.52
8A. Electricity: current direction	0.23	0.56
8B. Electricity: Ammeter reading	0.30	0.55
8C. Electricity: Current estimation	0.43	0.51
9A. Light: Concave mirror	0.36	0.54
9B. Light: Convex mirror	0.39	0.54
9C. Light: Plane mirror	0.50	0.53
10. Light: Lens image	0.06	0.58

Table 4.3 presents the item analysis for all 17 activities in terms of their acceptable levels of difficulty, and in terms of their ability to discriminate between high and low achievers on the compact programme as a whole.

To calculate the difficulty and the discrimination indices of the items the method described by Ebel (1972:384) has been used. Ebel suggested taking the upper and lower 27% of the achievers on the total test to perform the calculations of the individual item difficulty and discrimination indices. In this research study 27% of the 340 participants is 92 participants, so the achievements of the top 92 participants have been compared with those of the bottom 92 participants, item by item.

Table 4.3 Item analysis: indices of difficulty and discrimination

Item/ activity	NU (correct upper)	Correct Upper %	NL (correct lower)	Correct Lower %	(NU+NL)	Difficulty Index (%)	NU - NL	Index of Discrimination $D = \frac{NU - NL}{92}$
1	90	97.8	28	30.4	118	35.9	62	0.67
2	61	66.3	24	26.1	85	53.8	37	0.40
3A	52	56.5	22	23.9	74	59.8	30	0.33
3B	49	53.3	48	52.2	97	47.3	1	0.01
3C	57	62	35	38	92	50.0	22	0.24
4A	92	100	84	88	173	5.98	11	0.12
4B	92	100	80	87	172	6.52	12	0.13
5	47	51.1	11	12	58	68.5	36	0.39
6	51	55.4	45	48.9	96	47.8	6	0.07
7	71	77.2	9	9.78	80	56.5	62	0.67
8A	83	90.2	44	47.8	127	31.0	39	0.42
8B	58	63	17	18.5	75	59.2	41	0.45
8C	63	68.5	10	10.9	73	60.3	53	0.58
9A	78	84.8	26	28.3	104	43.5	52	0.57
9B	91	98.9	37	40.2	128	30.4	54	0.59
9C	77	83.7	19	20.7	96	47.8	58	0.63
10	28	30.4	17	18.5	45	75.5	11	0.12

In Table 4.3, the formula for calculating the item difficulty index is

$$d = \frac{(92 + 92) - (NU + NL)}{(92 + 92)} \times \frac{100}{1}$$

If the calculated difficulty index is less than 15% for a particular item, then that item is adjudged to be too easy. A difficulty index exceeding 85% suggests that the item is too hard.

The formula for calculating the index of discrimination, in this instance, is

$$D = \frac{(NU - NL)}{92}$$

Indices of discrimination are interpreted as follows:

$D > 0.50$  excellent;

$0.50 > D > 0.40$  very good;

$0.39 > D > 0.30$  good;

$0.29 > D > 0.20$  fair.

Table 4.3 justifies the retention of the queried item 2: *shoe pressure*. Its index of discrimination (0.40) is very good, and its difficulty level (53.8%) is close to the ideal of 0.50%.

Table 4.3 also justifies the retention of the queried item 5: *electricity: refrigerator bulb*. Its discrimination index (0.39) is also good, and its difficulty level (68.5%) is also acceptable.

However, activity 3B: *magnet B* is not only of dubious reliability; it also fails completely to discriminate between high and low achievers on the compact programme as a whole. However its level of difficulty (47.3%) is almost ideal.

Lastly, activity 4: *light globes* is perhaps too easy, while activity 6: *electricity: duration and activity* and activity 10: *lens image* are weak discriminators.



However, the main overall finding and conclusion arising from the results presented in Tables 4.1 to 4.3 is that all 17 practical task items will be provisionally retained in the compact programme for the next statistical analyses, because although several items are not entirely ideal in all the desirable aspects sought, they do have identifiable strengths.

Also, Figure 4.1 on page 112 depicts a near-normal distribution of scores on the programme as a whole by the diverse sample of  $n = 340$  participants. This is pleasing, since bimodal distributions tend to occur with teacher-made tests, unless the items are trialled and carefully refined, so this common mistake has been avoided in the formulation and compilation of the compact practical programme.

University of Cape Town

## 4.2 Section B: Presentation of the quantitative findings: hypothesis testing

In this section the total programme scores and individual item scores of different groups of participants are compared quantitatively according to various independent variables such as gender, home language, geographical area from which the participants came, etc. The phase 2 programme's population comprises N=340 participants, separated into various judicious samples according to the nature of the independent variable selected.

### 4.2.1 Academic level of school/institution as an independent variable

*H01a. Overall achievement of 308 secondary and 32 tertiary level students on the compact programme of 17 activities*

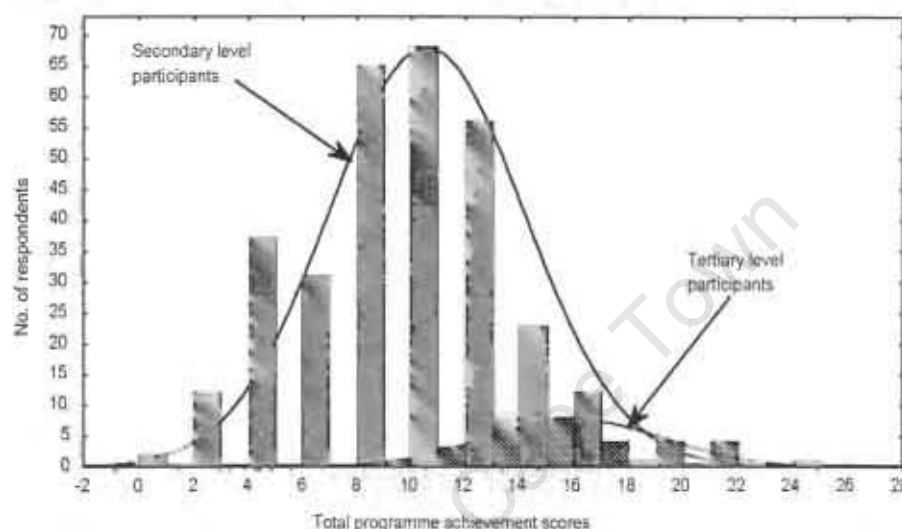
Null hypothesis 1a states: "That there will be no significant difference between the total achievement scores of the secondary students and the tertiary level students". Null hypothesis 1a is refuted. The findings presented in Table 4.4 show that the mean achievement score (out of 25) of the 32 tertiary level participants is 15.97, whereas the mean achievement score of the 308 secondary level participants is only 10.55. The difference is statistically significant. As expected, the tertiary sample has a better level of process skills in science than the secondary school sample. It is suggested that the compact programme might be a useful measure of level of process skill *development* but this cannot be concluded since English second language proficiency may also be a factor reducing performance achievement.

Table 4.4 A comparison of the total achievement test scores of the secondary level group and the tertiary level group

Secondary group			Tertiary group			t	df	p
n	Total test mean	SD	n	Total test mean	SD			
308	10.55	3.61	32	15.97	3.25	-8.15	338	0.000**

\*\*p<0.01

Figure 4.2 Scores of tertiary and secondary level participants



### *Ho1b. Achievements of secondary and tertiary level students on individual task items*

Null hypothesis 1b states: "That there will be no significant differences between the achievement scores of the high school students and the tertiary level students on each one of the 17 individual tasks comprising the ten basic items" taken individually. The findings presented in Table 4.5 show that significant differences occur between the achievement scores of the participants from the two different institutional levels on items 1, 2, 3A, 8A, 8B, 8C, 9A, and 9B. Thus, null hypothesis Ho1b is refuted for those eight test activities.

Note: Because the distributions of the scores for individual items are skewed, the chi-square test has been used, rather than t-tests.

Table 4.5 Comparisons of scores of secondary and tertiary level participants on individual items.

Item no	Maximum Score	Secondary group (n=308)		Tertiary group (n=32)		Chi-square value	P
		Mean	SD	Mean	SD		
1	3	1.74	1.33	2.59	0.76	8.77	0.003**
2	1	0.51	0.50	0.94	0.25	20.03	0.000**
3A	1	0.37	0.48	0.72	0.46	12.94	0.000**
3B	1	0.51	0.50	0.56	0.50	0.12	0.73
3C	1	0.44	0.50	0.63	0.49	3.36	0.067
4A	1	0.94	0.23	1.00	0.00	0.98	0.16
4B	1	0.94	0.25	1.00	0.00	1.19	0.13
5	3	0.73	0.90	0.78	1.13	0.61	0.44
6	1	0.26	0.439	0.44	0.50	44.89	0.053
7	2	0.50	0.62	0.97	0.93	1.34	0.25
8A	1	0.66	0.47	0.88	0.34	5.11	0.009**
8B	2	0.30	0.54	1.06	0.95	14.86	0.000**
8C	3	0.47	0.75	1.09	1.25	6.32	0.012*
9A	1	0.61	0.49	0.97	0.18	14.71	0.000**
9B	1	0.58	0.49	0.97	0.18	17.08	0.000**
9C	1	0.77	0.42	1.00	0.00	7.82	0.052
10	1	0.22	0.42	0.38	0.49	2.86	0.91

\* p&lt;0.05

\*\* p&lt;0.01

#### 4.2.2 Gender as an independent variable

##### *Ho2a. Overall achievement scores of the 157 males and 172 females*

Null hypothesis 2a states: "That there will be no significant difference between the total achievement scores of the 157 male and 172 female participants". The findings presented in Table 4.6 show that this hypothesis is tenable (i.e. is not rejected). The mean total achievement score of the 157 male participants is 10.90, which is not significantly different from the mean total achievement score of 11.27 for the 172 female participants.

Table 4.6 A comparison of the total test achievement scores of the females and males

Female group			Male group			t	df	P
n	Total test mean	SD	n	Total test mean	SD			
172	11.27	4.17	157	10.9	3.67	0.862	327	0.389

\*p&lt;0.05

*Ho2b. Achievement scores of males and females on individual items*

Null hypothesis 2b states: "That there will be no significant differences between the achievement scores of the males and females on each one of the 17 individual tasks comprising the ten items". The findings presented in Table 4.7 show that this hypothesis is rejected for items 2 and 10, but tenable for the other practical tasks. However, this isolated finding may be spurious, since item 2 has dubious reliability.

Table 4.7 Comparisons of the achievement scores of males and females on individual items

Item no.	Female group (n=172)		Male group (n=157)		df	Chi-square value	P
	Mean	SD	Mean	value			
1	1.715	1.32	1.924	1.30	327	2.33	0.13
2	0.616	0.49	0.471	0.50	327	6.39	0.012*
3A	0.459	0.50	0.350	0.48	327	3.60	0.058
3B	0.541	0.50	0.497	0.50	327	0.03	0.49
3C	0.448	0.50	0.465	0.50	327	0.10	0.75
4A	0.953	0.21	0.936	0.24	327	0.20	0.66
4B	0.965	0.18	0.917	0.28	327	2.64	0.104
5	0.791	0.96	0.656	0.88	327	0.48	0.49
6	0.267	0.44	0.293	0.46	327	0.15	0.35
7	0.773	0.65	0.599	0.69	327	0.51	0.48
8A	0.698	0.46	1.338	8.10	327	0.01	0.94
8B	0.424	0.66	0.318	0.60	327	2.35	0.13
8C	0.576	0.84	0.490	0.81	327	0.80	0.37
9A	0.686	0.47	0.605	0.49	327	2.02	0.16
9B	0.663	0.47	0.573	0.50	327	2.43	0.12
9C	0.791	0.41	1.439	8.01	327	0.00	0.99
10	0.186	0.39	0.306	0.46	327	5.76	0.016*

\*  $p < 0.05$

### 4.2.3 Grade level of the participants as an independent variable

#### *Ho3. Overall achievement scores of students from different grades*

Null hypothesis 3 states: "That there will be no significant differences between the total achievement scores of the high school students from each different grade level". The findings presented in Table 4.8 show that this null hypothesis is rejected for eight combinations of grade levels, six of which involve the tertiary sample.

Table 4.8 Comparisons between the total test achievement scores (out of 25) of participant groups at different grade levels.

Grades compared	Group 1 n	Group 2 n	Group 1 Mean	Group 2 Mean	t	df	p
Grade 8 vs. Grade 9	29	19	10.28	9.79	0.44	46	0.659
Grade 8 vs. Grade 10	29	91	10.28	9.42	1.09	118	0.278
Grade 8 vs. Grade 11	29	67	10.28	11.88	-1.78	94	0.078
Grade 8 vs. Grade 12	29	91	10.28	11.01	-1.14	118	0.256
Grade 8 vs. Tertiary level	29	32	10.28	15.97	-6.32	59	0.000**
Grade 9 vs. Grade 10	19	91	9.79	9.42	0.4	108	0.687
Grade 9 vs. Grade 11	19	67	9.79	11.88	-1.99	84	0.050*
Grade 9 vs. Grade 12	19	91	9.79	11.01	-1.67	108	0.097
Grade 9 vs. Tertiary level	19	32	9.79	15.97	-6.31	49	0.000**
Grade 10 vs. Grade 11	91	67	9.42	11.88	-3.94	156	0.000**
Grade 10 vs. Grade 12	91	91	9.42	11.01	-3.33	180	0.001**
Grade 10 vs. Tertiary level	91	32	9.42	15.97	-8.95	121	0.000**
Grade 11 vs. Grade 12	67	91	11.88	11.01	1.58	156	0.115
Grade 11 vs. Tertiary level	67	32	11.88	15.97	-4.89	97	0.000**
Grade 12 vs. Tertiary level	91	32	11.01	15.97	-8.39	121	0.000**

\* p<0.05

\*\* p<0.01

No significant differences are found between the following grade level pairs:

Between Grade 8 and Grades 9 to 12;

between Grade 9 and Grades 10 to 12; and

between Grade 11 and Grade 12.

#### 4.2.4 The test items' specified inclusion in the matriculation syllabus as an independent variable

Table 4.9 presents the mean scores obtained for items 1 to 10 by the sample of n=308 secondary level participants.

Table 4.9 Summary statistics for the performance on each of items 1 to 10 by the secondary level population of 308 participants

Items	n	Mean	Mean %	Max	SD
1. Displacement volume	308	1.74	57.90	3	1.33
2. Shoe pressure	308	0.51	50.85	1	0.50
3A. Magnet A	308	0.37	37.34	1	0.48
3B. Magnet B	308	0.51	51.30	1	0.50
3C. Magnet C	308	0.44	43.83	1	0.50
4A. Electricity: light globe cost	308	0.94	94.16	1	0.23
4B. Electricity: Light globe brightness	308	0.94	93.51	1	0.25
5. Electricity: Refrigerator light	308	0.73	24.24	3	0.90
6. Electricity: duration	308	0.26	25.97	1	0.44
7. Electricity: resistance	308	0.50	25.16	3	0.62
8A. Electricity: current direction	308	0.66	66.23	1	0.47
8B. Electricity: Ammeter reading	308	0.30	14.77	2	0.54
8C. Electricity: Current estimation	308	0.47	15.80	3	0.75
9A. Light: Concave mirror	308	0.61	61.04	1	0.49
9B. Light: Convex mirror	308	0.58	57.79	1	0.49
9C. Light: Plane mirror	308	0.77	77.27	1	0.42
10. Light: Lens image	308	0.22	22.40	1	0.42
Total score	308	10.55	42.21	25	3.61

The items numbered 1, 2, 9 and 10 (highlighted cells) are not mentioned specifically in the matriculation syllabus of the Western Cape Education Department. The specified items numbered 3, 4, 5, 6, 7 and 8 are included directly in the matriculation syllabus.

Table 4.10 presents a comparison of the total performance scores of the 340 participants on these two types of items, either unspecified in the syllabus or included in the syllabus (specified).

Table 4.10 Total performance scores of the 308 participants on six unspecified items and on eleven specified items, with reference to the matriculation syllabus

Items	Nature	n	Mean (%)	SD	t-value	df	p
1+2+9A+9B+9C+10	Unspecified	340	57.40	18.41	-0.90	678	0.38
3 to 8	Specified	340	45.58	28.94			

Null hypothesis 4 states, “That there will be no significant difference between the high school students’ achievement percentages on those items that are involved in the matriculation syllabus and on those items that are not”.

Ho4 is supported. The results presented in Table 4.10 show that there is no significant difference between the total performance scores of participants on those specified items that are included in matriculation and the unspecified items that are not included. The mean achievement of 57.40% on the items that are not involved in the matriculation syllabus is not significantly higher than the mean achievement of 45.58% on the items that are specifically involved in matriculation syllabus. The lack of statistical significance is due to the high values of the standard deviations of the test scores.

#### 4.2.5 English proficiency as an independent variable

##### *Ho5a. Overall achievement scores of participants according to their English proficiency levels*

Null hypothesis 5a states: “That there will be no significant difference between the total achievement scores of participants who are English first language speakers and ones who are not”. The findings presented in Table 4.11 reject this null hypothesis. The mean total achievement score for all English first language participants is 12.42 whereas the mean achievement score for all English second language participants is only 8.81. The difference in underachievement is highly significant ( $t=9.20$ ;  $df=338$ ;  $p<0.01$ ).



Table 4.11 The total achievement test scores of participants classified according to their English Language proficiency.

	n1	n2	Mean 1	Mean 2	t	df	p
All English first language vs. All English second language	212	128	12.42	8.81	9.20	338	0.000**
All English first language vs. Non-township English second language	212	19	12.42	10.95	1.78	229	0.76
All English first language vs. Township high school English second language	212	85	12.42	7.55	11.49	295	0.000**
High school English first language vs. Non-township high school English second language	184	19	11.89	10.95	1.22	201	0.22
High school English first language vs. Township high school English second language	184	85	11.89	7.55	10.74	267	0.000**
Non-township high school English second language vs. Township high school English second language	19	85	10.95	7.55	5.03	102	0.000**

In Table 4.11, "All English first language" refers to all of the 212 English first language participants, "All English second language" refers to all of the 128 English second language participants, "Township high school English second language" refers to the participants who are at the high schools situated in Townships, "Non-township English second language" refers to English second language participants who are **not** at schools in geographically underprivileged areas such as Townships.

Figure 4.3. Total achievement scores of participants classified according to their English language proficiency

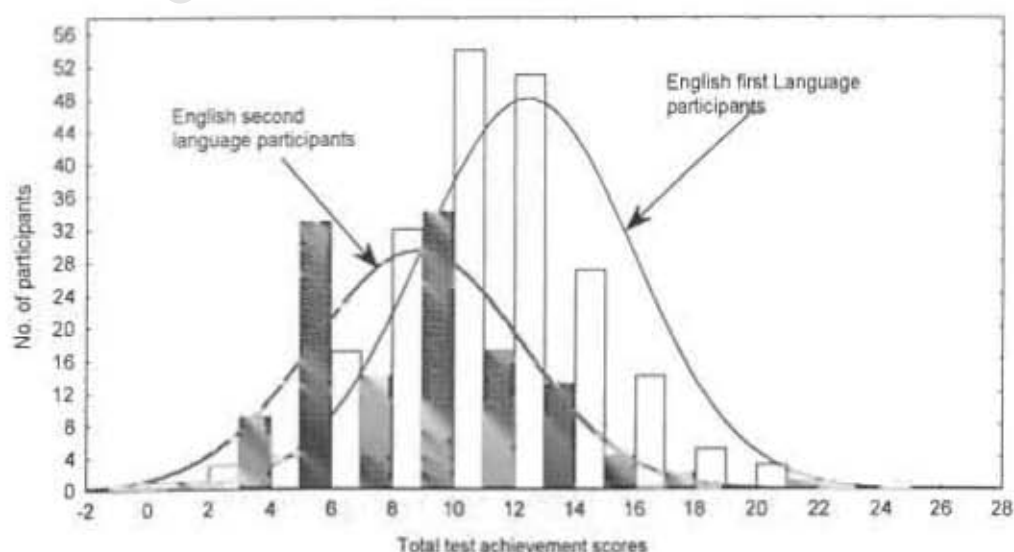
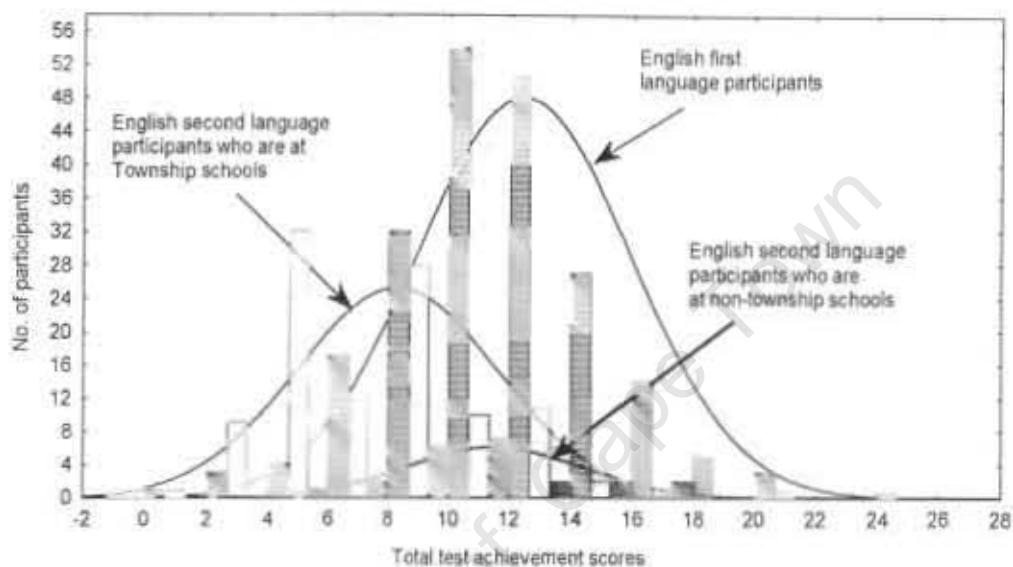


Figure 4.3 shows the frequencies of total achievement scores of English first language participants and English second language participants. Figure 4.3 also presents the distributions of total achievement scores of English first and second language participants. However, it distinguishes between two types of English second language participants who are at schools situated in privileged and underprivileged areas.

Figure 4.4. Total achievement scores of participants according to their English proficiency levels and geographical locations



#### *Ho5b. Achievements of participants according to their English proficiency levels on individual tasks*

The null hypothesis 5b states: "That there will be no significant differences between the achievement scores of participants who are English first language speakers and who are not, on each one of the 17 individual task items". The findings presented in Table 4.12 show that this null hypothesis is tenable (i.e. is not rejected) for items 3A, 3C, 4A, 4B, and 10 but is rejected for items 1, 2, 3B, 5, 6, 7, 8A, 8B, 8C, 9A, 9B and 9C. English first language participants achieved significantly higher mean scores than English second language participants on items 1, 2, 6, 7, 8B, 8C, 9A and 9B, but on tasks 3B, 5, 8A and 9C the English second language participants scored higher.

Table 4.12 Comparison of scores of English first language ( $n_1$ ) and English second language speaking participants ( $n_2$ ) on each item individually.

	$n_1$	$n_2$	$M_1$	$SD_1$	$M_2$	$SD_2$	df	Chi-square value	p
1. Displacement volume	212	128	2.36	1.04	0.91	1.22	338	86.77	0.000**
2. Shoe pressure	212	125	0.60	0.49	0.46	0.50	335	5.93	0.015*
3A. Magnet A	212	128	0.42	0.49	0.38	0.49	338	0.31	0.58
3B. Magnet B	212	128	0.46	0.50	0.62	0.50	338	6.03	0.014*
3C. Magnet C	212	128	0.44	0.50	0.48	0.50	338	0.23	0.63
4A. Electricity: light globe cost	212	128	0.95	0.50	0.94	0.24	338	0.13	0.72
4B. Electricity: Light globe brightness	212	128	0.95	0.50	0.93	0.26	338	0.21	0.64
5. Electricity: Refrigerator light	212	128	0.65	0.50	0.88	0.50	338	20.50	0.000**
6. Electricity: duration	212	128	2.24	0.21	0.95	0.24	338	14.50	0.000**
7. Electricity: resistance	212	128	0.73	0.22	0.24	0.26	338	41.00	0.000**
8A. Electricity: current direction	212	128	0.73	0.95	1.40	0.87	338	5.60	0.026*
8B. Electricity: Ammeter reading	212	128	0.45	0.44	0.23	0.46	338	5.00	0.000**
8C. Electricity: Current estimation	212	128	0.69	0.70	0.27	0.47	338	17.73	0.000**
9A. Light: Concave mirror	212	128	0.92	0.27	0.49	0.50	338	19.62	0.000**
9B. Light: Convex mirror	212	128	0.74	0.70	0.43	0.46	338	32.00	0.000**
9C. Light: Plane mirror	212	128	0.92	0.92	1.37	0.55	338	56.48	0.000**
10. Light: Lens image	212	128	0.23	0.44	0.26	0.50	338	0.28	0.60

\*  $p < 0.05$ \*\*  $p < 0.01$ 

#### 4.2.6 The participants' schools/institutions as an independent variable

*Ho6a. Overall achievement scores of participants and their schools/institutions.*

The null hypothesis 6a states: "That there will be no significant differences between the total achievement scores of the groups of participants classified according to their schools/institutions". The findings presented in Table 4.13 show that this null hypothesis is rejected. The mean scores range from a low of 7.53 for *school 30* to a high of 15.97 for *school 40*. Only *school 10* and *school 50* have comparable mean scores.

Table 4.13 Comparison of total achievements of different schools

School	n <sub>1</sub>	n <sub>2</sub>	M <sub>1</sub>	SD <sub>1</sub>	M <sub>2</sub>	SD <sub>2</sub>	t-value	df	p
10 vs. 20	98	48	10.91	3.42	11.98	1.54	-2.07	144.0	0.041*
10 vs. 30	98	86	10.91	3.42	7.53	2.66	7.39	182.0	0.000**
10 vs. 40	98	32	10.91	3.42	15.97	3.25	-7.35	128.0	0.000**
10 vs. 50	98	34	10.91	3.42	10.62	3.45	0.43	130.0	0.671
10 vs. 60	98	42	10.91	3.42	14.21	2.75	-5.54	138.0	0.000**
20 vs. 30	48	86	11.98	1.54	7.53	2.66	10.62	132.0	0.000**
20 vs. 40	48	32	11.98	1.54	15.97	3.25	-7.38	78.0	0.000**
20 vs. 50	48	34	11.98	1.54	10.62	3.45	2.42	80.0	0.018*
20 vs. 60	48	42	11.98	1.54	14.21	2.75	-4.84	88.0	0.000**
30 vs. 40	86	32	7.53	2.66	15.97	3.25	-14.40	116.0	0.000**
30 vs. 50	86	34	7.53	2.66	10.62	3.45	-5.24	118.0	0.000**
30 vs. 60	86	42	7.53	2.66	14.21	2.75	-13.20	126.0	0.000**
40 vs. 50	32	34	15.97	3.25	10.62	3.45	6.48	64.0	0.000**
40 vs. 60	32	42	15.97	3.25	14.21	2.75	2.52	72.0	0.014*
50 vs. 60	34	42	10.62	3.45	14.21	2.75	-5.07	74.0	0.000**

\* p&lt;0.05

\*\* p&lt;0.01

*School 40* achieved significantly higher total scores than all the other schools, except for *school 60*.

***Ho6b. The participants' schools/institutions and their achievement scores on individual tasks***

Null hypothesis 6b states: "That there will be no significant differences between the achievement scores of participants from different schools on individual tasks". This null hypothesis is partially rejected. For example, for item 3 Table 4.14 shows no significant differences between some pairs of schools, but significant achievement difference between other pairs of schools.

Table 4.14 Comparisons of schools/institutions on item 3 (magnet pole)

Task	School	n <sub>1</sub>	n <sub>2</sub>	M <sub>1</sub>	SD <sub>1</sub>	M <sub>2</sub>	SD <sub>2</sub>	t-value	df	p
3A	10 vs. 20	98	48	0.42	0.50	0.48	0.50	-0.69	144	0.490
	10 vs. 30	98	86	0.42	0.50	0.29	0.46	1.81	182	0.072
	10 vs. 40	98	32	0.42	0.50	0.72	0.46	-3.03	128	0.003**
	10 vs. 50	98	34	0.42	0.50	0.41	0.50	0.07	130	0.947
	10 vs. 60	98	42	0.42	0.50	0.29	0.46	1.48	138	0.140
	20 vs. 30	48	86	0.48	0.50	0.29	0.46	2.20	132	0.029*
	20 vs. 40	48	32	0.48	0.50	0.72	0.46	-2.16	78	0.034*
	20 vs. 50	48	34	0.48	0.50	0.41	0.50	0.60	80	0.551
	20 vs. 60	48	42	0.48	0.50	0.29	0.46	1.89	88	0.061*
	30 vs. 40	86	32	0.29	0.46	0.72	0.46	-4.53	116	0.000**
	30 vs. 50	86	34	0.29	0.46	0.41	0.50	-1.27	118	0.205
	30 vs. 60	86	42	0.29	0.46	0.29	0.46	0.06	126	0.954
	40 vs. 50	32	34	0.72	0.46	0.41	0.50	2.60	64	0.012*
	40 vs. 60	32	42	0.72	0.46	0.29	0.46	4.04	72	0.000**
	50 vs. 60	34	42	0.41	0.50	0.29	0.46	1.15	74	0.255
3B	10 vs. 20	98	86	0.53	0.50	0.58	0.50	-0.69	182	0.492
	10 vs. 30	98	32	0.53	0.50	0.56	0.50	-0.31	128	0.756
	10 vs. 40	98	34	0.53	0.50	0.53	0.51	0.01	130	0.990
	10 vs. 50	98	42	0.53	0.50	0.31	0.47	2.44	138	0.016*
	10 vs. 60	48	86	0.52	0.50	0.58	0.50	-0.67	132	0.502
	20 vs. 30	48	32	0.52	0.50	0.56	0.50	-0.36	78	0.718
	20 vs. 40	48	34	0.52	0.50	0.53	0.51	-0.08	80	0.940
	20 vs. 50	48	42	0.52	0.50	0.31	0.47	2.05	88	0.043*
	20 vs. 60	86	98	0.58	0.50	0.53	0.50	0.69	182	0.492
	30 vs. 40	86	48	0.58	0.50	0.52	0.50	0.67	132	0.502
	30 vs. 50	86	32	0.58	0.50	0.56	0.50	0.18	116	0.855
	30 vs. 60	86	34	0.58	0.50	0.53	0.51	0.51	118	0.608
	40 vs. 50	86	42	0.58	0.50	0.31	0.47	2.96	126	0.004**
	40 vs. 60	32	34	0.56	0.50	0.53	0.51	0.27	64	0.791
	50 vs. 60	32	42	0.56	0.50	0.31	0.47	2.23	72	0.029*
3C	10 vs. 20	98	48	0.50	0.50	0.52	0.50	-0.23	144	0.815
	10 vs. 30	98	86	0.50	0.50	0.58	0.50	-1.10	182	0.272
	10 vs. 40	98	32	0.50	0.50	0.56	0.50	-0.61	128	0.543
	10 vs. 50	98	34	0.50	0.50	0.53	0.51	-0.29	130	0.770
	10 vs. 60	98	42	0.50	0.50	0.31	0.47	2.10	138	0.038*
	20 vs. 30	48	86	0.42	0.50	0.42	0.50	-0.02	132	0.983
	20 vs. 40	48	32	0.42	0.50	0.63	0.49	-1.84	78	0.069*
	20 vs. 50	48	34	0.42	0.50	0.56	0.50	-1.27	80	0.209
	20 vs. 60	48	42	0.42	0.50	0.26	0.45	1.54	88	0.126
	30 vs. 40	86	32	0.42	0.50	0.63	0.49	-2.01	116	0.046*
	30 vs. 50	86	34	0.42	0.50	0.56	0.50	-1.39	118	0.168
	30 vs. 60	86	42	0.42	0.50	0.26	0.45	1.73	126	0.085
	40 vs. 50	32	34	0.63	0.49	0.56	0.50	0.54	64	0.592
	40 vs. 60	32	42	0.63	0.49	0.26	0.45	3.32	72	0.001**
	50 vs. 60	34	42	0.56	0.50	0.26	0.45	2.73	74	0.008**

\* p&lt;0.05

\*\* p&lt;0.01

#### 4.2.7 Participants' degree of familiarity with the apparatus as a correlate

***Ho7a. Correlation between scores of overall achievement and “home familiarity” scores***

Null hypothesis 7a states: “That there will be no significant correlation between the total achievement scores of participants and their scores for total “*home familiarity*” with the apparatus”. The findings presented in Table 4.15 show that this null hypothesis is rejected. The biserial correlation between the participants’ “*home familiarity*” and their total achievement scores  $r=0.24$  is a low but a statistically significant correlation ( $p<0.01$ ,  $N=340$ ).

Table 4.15 Biserial correlations between total achievement scores and the participants’ familiarity with the apparatus ( $N=340$ )

	Home familiarity	School familiarity	Overall familiarity
Total Score	0.24	0.24	0.31
p	0.000	0.000	0.000

***Ho7b. Correlation between scores of overall achievement and “school familiarity” scores***

Null hypothesis 7b states: “That there will be no significant correlation between the total achievement scores of participants and their scores for total “*school familiarity*” with the apparatus”. The findings presented in Table 4.14 show that this null hypothesis is rejected. The biserial correlation of  $r=0.24$  is a low but statistically significant one ( $p<0.01$ ,  $N=340$ ).

***Ho7c. Correlation between scores of overall achievement and “overall familiarity” scores***

Null hypothesis 7c states: “That there will be no significant correlation between the total achievement scores of participants and their scores for total “*overall familiarity*” with the apparatus. The findings presented in Table 4.14 show that this null hypothesis is rejected. The value for the biserial correlation coefficient

of  $r=0.31$  is low but is, nevertheless, a statistically highly significant one ( $p<0.01$ ,  $N=340$ ).

***Ho8. Correlations between participants' achievement scores on individual items and their "extent of familiarity" with the apparatus used in particular items***

In this section "Extent of Familiarity" refers to the participants' total familiarity with each item of apparatus (Home Familiarity +School Familiarity).

Table 4.16 Correlations between participants' achievement scores and the extent of their familiarity with the apparatus in individual test item

		Achievement scores															
N=340		Item 1	Item 3A	Item 3B	Item 3C	Item 4A	Item 4B	Item 5	Item 6	Item 7	Item 8A	Item 8B	Item 8C	Item 9A	Item 9B	Item 9C	Item 10
Familiarity	Item 1	0.35															
	Item 3		-0.07	0.03	-0.01												
	Item 3		0.03	-0.09	-0.05												
	Item 4					-0.05	0.02										
	Item 5							-0.02									
	Item 6								-0.12								
	Item 7									0.13							
	Item 8										0.01	-0.04	0.06				
	Item 9A													0.00			
	Item 9B														0.04		
	Item 9C															-0.02	
Item 10																-0.11	

The null hypothesis 8 states: "That for individual items, there will be no significant correlation between the achievement scores of participants and their "extent of familiarity" with the apparatus that was used in the particular item". The statistical analysis of the data collected from the participants shows that this null hypothesis is tenable (i.e. is not rejected). No significant correlation was found between participants' achievement scores on individual items and the extent of their familiarity with apparatus in particular items.

4.2.8 Summary of achievements of different samples

Table 4.17 summarizes the mean performance levels obtained on the compact programme by the various types of samples and groups participating in this study. It can be seen that the group of tertiary participants achieved the highest mean score which is almost double the mean score obtained by the lowest achieving group – English second language speakers.

Table 4.17 Summary of the mean performance scores of the participating groups on the whole test

Group	n	Mean	SD
Tertiary level participants	32	15.97	3.25
Secondary school learners	308	10.55	3.61
Grade 12	91	11.01	2.74
Grade 11	67	11.88	4.16
Grade 10	91	9.42	3.66
Grade 9	19	9.79	3.60
Grade 8	29	10.28	3.79
Female participants	172	11.27	4.17
Male participants	157	10.90	3.67
English prime language participants	212	12.42	3.52
English second language participants	128	8.81	3.48

4.3 Section C: Presentation of the qualitative findings

The qualitative findings of the research comprise an analysis of the tape-recorded and written comments and observations of the participants while they were responding to and evaluating the practical test items and activities.

The classification and debates about the theories of learning science, assessment frameworks and learning outcomes will also be discussed in this section in relation to the evidence collected and presented.



The participants were asked to write down their comments about the practical test items on the record sheet provided. A total of 408 comments made by 340 responding participants tended to focus on the following themes: -

1. Affective responses to the tasks.
2. Process skill responses.
3. The value of the programme for learning.
4. The difficulty of the practical items.
5. The demands and enthusiasm of the participants for more practical assessment activities and practical science tasks.
6. Science as a school subject.

The tape-recorded and written comments made by various participants are now gathered, presented and analysed under these six themes. Appendix 4 contains photocopies of the handwritten responses, representative of the themes.

#### **4.3.1 Affective responses to the tasks**

Some of the written comments made by the participants focused on their feelings and emotional responses to the tasks presented in this study. Their most frequent affective response words used to describe the programme are listed in table 4.18.

Table 4.18 Affective response words written by participants in the programme to describe the tasks and activities and their frequencies

Words	Frequencies
Interesting	83
Good	76
Enjoyable	51
Fun	43
Exciting	16
Challenging	7
Stimulating	3
Interactive	1
Different	1
Unusual	1
Informative	1
Nice	1
Confusing	1

### **Expression of interest**

Examples of the participants' written comments quoted verbatim were: -

- *"I feel that this test was very unique and different. It was unusual but very interesting".*
- *"This is interesting way of learning".*
- *"I find electricity quiet interesting because it is applicable".*
- *"Magnifying glasses were very interesting".*
- *"I found magnets and mirrors aspects more interesting".*

### **Expression of goodness**

- *"I felt that this exercise was a good method for determining prior knowledge".*
- *"This is a very good way of learning".*

### **Expression of enjoyment and fun**

- *"I enjoyed this it was fun".*
- *"I especially enjoyed the mirrors".*
- *"I really enjoyed looking at the objects. I would rather prefer this to the teacher explaining them to us".*

### **Combinations**

One participant wrote *"The practical test was different, but I think different methods make it much more exciting"*.

One high school learner pointed to the importance of allowing learners to do individual practicals.

Participants expressed mostly positive opinions on the programme. Some said it is more appealing to the participants than using textbook only, or their teachers explaining this type of teaching on the board. However it was also stated in the student comments that practical and theory must be mixed, i.e. neither must be left out. One participant wrote, *"It must be done and it must be explained afterwards"*. Two other participants wrote, *"This is a very good way of learning, it cannot all be taught like this. It should also be explained by teacher"*.

Other participants did not specifically indicate their opinions about physics but they wrote their comments with a positive attitude: -

- *"I agree that basic science is necessary for everyday life"*.
- *"Magnifying glasses were very interesting"*.
- *"I especially enjoyed the mirrors"*.
- *"Thank you for a very nice lesson"*.

#### **4.3.2 Process skill responses**

Table 4.19 records process skills word and terms which the programme was attempting to foster among the participants (Revised National Curriculum Statement Draft 2001:99-100). It also records the number of times these words, or their equivalent, appeared among the qualitative comments spontaneously offered by the participants when they completed the programme evaluation sheet (Figure 3.12 The comment sheet), or which appeared in the tape recording of the group work sessions.

Thus, Table 4.18 provides independent evidence to substantiate by triangulation the claim of this investigation that the experimental programme of materials and activities succeeded, at least in part, in attaining some of the intended outcomes in respect to fostering awareness of science process skills as they were being used by the participants.

University of Cape Town

Table 4.19 Process skill words and terms spontaneously used by 340 participants in the programme to describe their activities with the items and apparatus (including tape-recorded words and phrases)

Words (or their equivalent) spoken or written by the participants	Frequency
Handling, touching, experiencing	29
Observing, watching, looking for	11
Reflecting, re-examining, looking back, reviewing, remembering	11
Conceiving and idea applying	9
Answering	7
Experimenting, happening, doing, investigating, carrying out	5
Explaining, inferring, reasoning	4
Solving the problem	4
Suggesting, hypothesizing, thinking of possibilities	3
Listening	2
Making sense of	2
Changing	1
Completing, filling in	1
Deciding relevance	1
Estimating, guessing, suggesting	1
Improving	1
Improvising	1
Inventing, making, devising	1
Planning, devising, formulating	1
Raising questions about	1
Using instruments	1
Working together	1
Assigning roles, duties, tasks	0
Choosing	0
Clarifying, simplifying	0
Collecting	0
Comparing	0
Concluding	0
Constructing	0
Discussing	0
Finding a rule, a connection, a relationship or a pattern	0
Finding a way	0
Generalising	0
Interpreting	0
Making more reliable	0
Measuring	0
Modelling	0
Predicting, anticipating	0
Questioning	0
Recording, writing about	0
Referring	0
Re-focusing	0
Reporting, communicating, telling	0
Seeking	0
Sequencing	0
Sketching, tracing, drawing, photographing	0
Sorting, classifying, grouping	0

### 4.3.3 The perceived value of the programme for learning

This section presents the comments of participants who focused on the value of practice, i.e. on how it enhanced their learning experiences. A total of 88 participants specifically mentioned in their comments that the programme provided advantages for learning science. They emphasised that this type of experiential instructional methodology made it easier to picture the specific topics in science, and easier to understand them.

Although the nature of the activity involved in the study was largely a practical self-assessment, the participants emphasised that it should be used more often as a method of teaching. Participants wrote:-

- *"I would like to have another (practical) test because the more we test ourselves the more we learn".*
- *"It makes me want to learn more".*
- *"It makes me feel better".*
- *"I pick up information more quickly when I observe and do it".*
- *"It is easier to understand when all five senses are involved".*
- *"I think practicals allow you to learn more efficiently because you come to your own conclusions".*
- *"I learn better from this".*

Another aspect of the practice commented on was that basic science is easier to remember when it is taught through practical methods. Fifteen participants particularly noted that they remember something better when they physically see and have contact with real objects: -

- *"I remember things better when I work with actual apparatus".*
- *"It is easy to remember".*
- *"I have done these exercises in Grade 8 and 9 and I still have not forgotten them".*
- *"I don't like experiments because people crowd on experiments and we usually do not have time to think".*

Seven participants advocated that learning would be enhanced if the practical programme were combined with other teaching methods such as textbook, or a teacher explaining on the board, etc.: -

- *"I would like it to be explained further".*
- *"Science is a very intense subject and should be made interesting by alternative methods".*
- *"This method should be combined with the textbook and used in future".*
- *"Practical work and theory must be mixed".*
- *"This is a very good way of learning, it cannot all be taught like this. It should also be explained by teacher".*

#### **4.3.4 The difficulty of the practical items**

An open ended question posed to the participants asked whether or not they found the test difficult. Thirty participants indicated that the practical tasks, either partially or as a whole, were difficult whereas 65 participants indicated that they did not find the programme difficult. Some of the comments made on this aspect included: -

- *"It is very difficult yet very interesting".*
- *"I didn't find it difficult".*
- *"I find the practical test difficult".*

#### **4.3.5 The personal demands and enthusiasm of participants for practical assessment and practical science tasks**

One of the major themes that emerged in the oral and written comments of the participants was the frequent demand of the participants for the practical programme. They were invited to indicate whether it should form a part of classroom practice or whether it should be excluded from classroom practice. 143 participants indicated that they strongly supported the practice and that such programmes should be conducted in classrooms regularly. Some of the participants wrote: -

- *"I think it definitely should be used in classroom practice as it is easier to remember once the theory is put to practice".*
- *"Please give us more practical tests so that we can get familiar with the practical experience. Please come back again and again!"*
- *"I hope that we can have tests like this in other subjects as well".*
- *"I hope we can do it again".*
- *"It should be included in classroom practice".*

#### 4.3.6 Science as a school subject

Some of the participants commented on their past experiences of science as a school subject. Eleven participants indicated that they do not like science and that they dislike physics in particular. These participants were high school students who were not taking physical science as a subject. They wrote: -

- *"The word "science" makes me nervous".*
- *"I hate science but I don't mind practical work".*
- *"When I was younger I used to enjoy science. It got progressively harder and harder and more confusing. Now I just don't understand it".*

Other participants commented on their experiences of the content of the science as a subject: -

- *"Science at school is much more technical than what I need to know for day-to-day life".*
- *"Everyone's goal should be to learn the universe therefore it is important to understand science concepts".*
- *"We must show the learners practical applications of concepts" (An educator's tape-recorded comment during a discussion on how to get learners in science more actively.)*

#### 4.3.7 Summary

The important substantive issues embedded in the 408 written comments appear to emerge as: the necessity for teachers continuously to make science more interesting; to relate school science to the everyday lives of the learners; the importance of motivating the learners to participate in classroom activities; and



the necessity for setting alternative targets for learners who do not plan to pursue a career directly related to science.

Some of the important relationships highlighted included the attitudes of participants towards science and their perceptions of the difficulty and nature of the subject as documented in Appendices 3 and 4. Unexpected perspectives mentioned by students were: a negative attitude towards homework and textbooks; the perception of many high school learners that science is necessary but mostly uninteresting; the importance/desirability of involving computer-related issues in science; and the suggestion that this type of programme practice should be used in other school subjects.

Patterns of written responses tended to concentrate on the participants' experiences with and opinions of the practical tasks, and of science as a school subject. Categories and descriptions such as "interesting", "difficult", "confusing", "easy to remember" and "school science" were used to identify important emerging themes such as the affective response to the tasks, the value of the programme and the difficulty of the practical items.

Current issues or words in science which received little or no mention on the open-ended comment sheets were: gender; globalization; poverty; medium of language instruction; time allocation; scientific ethics; the costs of the apparatus; level of participation; the method of displaying the items; the participants' own grade levels and the academic levels of the practical tasks; the relation of the practical tasks to matriculation examination requirements; and the intended future careers of the school learners.

In chapter 5 these issues will be discussed in more detail in the context of the wider literature published in the field of science education.

#### **4.4 Section D: Evaluation of the design, context and structure of the compact programme in terms of eight different theories of practical work**

One of the purposes of this investigation is to gauge the extent to which the present compact programme of 17 practical activities in basic physics can be considered to in harmony with recent and current theories and conceptual frameworks of school science practical work. If there is a mis-match or a lack of congruence in some respect, then either some of the theories themselves may require modification or some aspects of the compact programme itself might require amendment.

Thus, one of the outcomes of this section of the dissertation will be the identification of the stronger theories of the design and implementation of practical work for basic high school physical science. Data was collected from “juries of experts” typically comprising discussant groups of 8 to 12 professional science and technology teachers and academics.

The participants were provided with differently coloured classification cards (Appendix 6) on which were written explanatory details of theories used in this research. The classroom experts were asked to rate the relevance of each component of every theory to each one of the ten individual items in the compact programme of practical work. Their consensus responses are presented in Tables 4.20 to 4.26. A sample copy of these classification cards is attached in Appendix 6.

Table 4.20 How relevant are the various aspects of Gardner's theory of multiple intelligence to the compact programme of practical activities? The consensus views of eight science/technology educators on a scale of 0 to 3.

	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Total
G Ling	2	2	2	2	2	2	2	2	2	2	20
G LM	2	2	3	2	3	2	3	2	2	3	24
G Spat	2	2	1	1	2	1	0	0	2	2	14
G BK	3	2	3	1	2	3	3	3	3	3	26
G Mus	0	0	0	0	0	0	0	0	0	0	0
G Inter	0	0	0	0	0	0	0	0	0	0	0
G Intra	0	0	0	0	0	0	0	0	0	0	0
Total	7	7	10	7	9	8	8	9	9	10	

Table 4.21 How relevant are the various aspects of Franus' subsystems of thinking to the compact programme of practical activities? The consensus views of eight science/technology educators on a scale of 0 to 3.

	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Total
F Cog	1	1	1	2	2	2	3	2	1	2	17
F Tech	3	1	3	1	2	2	3	3	1	2	21
F Art	0	0	0	0	0	0	0	0	0	0	0
F Mus	0	0	0	0	0	0	0	0	0	0	0
F Lit	2	2	2	2	2	2	2	2	2	2	20
Total	6	4	6	5	6	6	8	7	4	6	

Table 4.22 How relevant are the various aspects of White's components of memory to the compact programme of practical activities? The consensus views of eight science/technology educators on a scale of 0 to 3.

	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Total
W Str	1	2	3	2	2	2	2	3	1	2	20
W Prop	2	3	3	2	3	2	3	3	1	2	24
W Img	1	2	2	3	3	2	1	2	3	2	21
W Epi	1	1	2	3	2	2	1	1	1	3	17
W Int	2	2	3	2	3	2	3	3	3	2	25
W Mot	3	2	3	1	2	3	3	3	3	3	26
W Cog	2	2	1	2	2	2	3	2	1	2	19
Total	12	14	17	15	17	15	16	17	13	16	

Table 4.23 How relevant are the various aspects of Lock's assessment framework for practical skills to the compact programme of practical activities? The consensus views of eight science/technology educators on a scale of 0 to 3.

	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Total
L Obs	3	2	3	2	2	2	3	3	3	3	26
L Man	3	2	3	1	2	3	3	3	3	3	26
L Interp	2	2	3	2	2	2	2	3	2	2	22
L Plan	3	2	3	1	2	2	2	2	2	3	22
L Rep	2	1	3	1	2	3	2	3	1	2	20
Total	13	9	15	7	9	12	12	14	10	11	112

Table 4.24 How relevant are the various aspects of Solomon's multiple dimensions of the public understanding of science to the compact programme of practical activities? The consensus views of eight science/technology educators on a scale of 0 to 3.

	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Total
S Ind	2	1	2	2	2	2	1	2	2	1	17
S Prof	2	1	2	2	2	2	3	3	2	1	20
S Rat	1	2	2	1	2	2	3	3	2	2	20
S Hum	1	2	1	2	2	1	1	1	2	2	15
Total	6	6	7	7	8	7	8	9	8	6	72

Kapenda et al. (2001) examined the practical work conducted in Namibian schools with regard to the aspects of task design (inductive-deductive, open-closed and nature of student involvement) and context of practical work (duration, interaction patterns, types of task information and apparatus and nature of the student record). The practical tasks in this investigation have also been classified and evaluated according to the same criteria. The criteria used are organised as presented the Table 4.24 below.

Table 4.25 How relevant are the various criteria of practical tasks used by Kapenda et al. to the compact programme of practical activities? The consensus views of eight science/technology educators on a scale of 0 to 3.

	Criteria	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Total
Aspects of task design	Inductive (KA 1)	1	1	2	1	1	2	1	2	2	1	14
	Deductive (KA 2)	2	1	2	2	2	2	2	2	2	2	19
	Open (KA 3)	1	1	1	1	1	1	1	1	1	1	10
	Closed (KA 4)	2	1	2	2	1	2	2	1	1	1	15
	Student involvement (KA 4)	3	3	2	3	2	3	3	3	3	3	28
Context of practical work	Duration (KC 1)	3	3	3	3	3	3	3	3	3	3	30
	Student interaction (KC 2)	1	1	1	1	1	1	1	1	1	1	10
	Types of task information and apparatus (KC 3)	3	2	3	2	2	2	3	2	2	2	23
	Student record (KC 4)	3	3	3	3	3	3	2	2	2	3	27

### Relevance of OBE's outcomes

Curriculum 2005 has been restructured recently as Revised National Curriculum Statement Draft (2001) that has just been released. Different from Curriculum 2005, the Learning Area Natural Sciences has been divided into four main strands and the nine former learning outcomes of the learning area have now been replaced with the following three outcomes (p 18):-

1. The learner is able to develop and use science process skills in a variety of settings (LO 1).
2. The learner is able to develop and apply scientific knowledge and understanding (LO 2).
3. The learner is able to gain an appreciation of the relationship and responsibilities between science and society (LO 3).

The relevance of the 17 practical tasks in the present compact programme to the three learning outcomes set by Revised National Curriculum Statement Draft (2001) has been investigated and discussed by the jury of eight experts in the field of science and technology education and the following table has been produced by consensus.

Table 4.26 How relevant are the practical activities to learning outcomes suggested by OBE? The consensus views of eight science/technology educators on a scale of 0 to 3.

Learning outcomes	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Total
LO 1	3	2	3	2	2	3	3	3	3	3	27
LO 2	3	3	3	3	2	2	2	2	2	3	25
LO 3	1	2	1	3	3	1	1	2	2	1	17
Total	7	7	7	8	7	6	6	7	7	7	

An overall comparison of the perceived relevance of the compact programme to the seven of eight selected theories, frameworks and criteria for science practical work is tabulated below, Table 4.26.

Table 4.27 Analysis of the degree of relevance of the theories to the compact programme of practical activities, as assessed by ten science/technology educators

	No. of items classified	Mean (out of 3)	Sum	Minimum	Maximum	Overall mean
G Ling	10	2	20	2	2	2.13
G LM	10	2.4	24	2	3	
G Spat	10	1.5	15	0	3	
G BK	10	2.6	26	1	3	
G Mus	10	0	0	0	0	Not relevant factors
G Inter	10	0	0	0	0	
G Intra	10	0	0	0	0	
F Cog	10	1.7	17	1	3	1.93
F Tech	10	2.1	21	1	3	
F Lit	10	2	20	2	2	
F Art	10	0	0	0	0	Not relevant factors
F Mus	10	0	0	0	0	
W Str	10	2	20	1	3	2.17
W Prop	10	2.4	24	1	3	
W Ing	10	2.1	21	1	3	
W Epi	10	1.7	17	1	3	
W Int	10	2.5	25	2	3	
W Mot	10	2.6	26	1	3	
W Cog	10	1.9	19	1	3	
L Obs	10	2.6	26	2	3	2.32
L Man	10	2.6	26	1	3	
L Interp	10	2.2	23	2	3	
L Plan	10	2.2	21	1	3	
L Rep	10	2	20	1	3	
S Ind	10	1.7	17	1	2	1.80
S Prof	10	2	20	1	3	
S Rat	10	2	20	1	3	
S Hum	10	1.5	15	1	2	
KA 1	10	1.4	14	1	2	1.45
KA 2	10	1.9	19	1	1	

KA 3	10	1,0	10	1	2	2.28
KA 4	10	1,5	15	1	2	
KC 1	10	2,8	28	2	3	
KC 2	10	3,0	30	3	3	
KC 3	10	1,0	10	1	1	
KC 4	10	2,3	23	2	3	2.3
LO 1	10	2,7	27	2	3	
LO 2	10	2,5	25	2	3	
LO 3	10	1,7	17	1	3	

Although the sizes of the “panels of professional science educators” or “juries of experts” might be considered small, they did tend to reach almost unanimous consensus in their classifications of the relevance of the practical activities. It can be provisionally concluded from Table 4.27 that the theories of science practical work which most closely match the compact programme of practical activities are those of

- “LO1 + LO2 + LO3”, i.e. Outcomes-Based Education’s Revised National Curriculum Statement Draft (2001); and
- “KC1 + KC2 + KC3 + KC4”, i.e. the theoretical criteria for practical activities advocated by Kapenda et al. (2001); and
- “L Obs , L Man, L Interp, L Plan, L Rep”, i.e. the assessment framework for practical skills of Lock (1989).

The least relevant theory appears to be the criteria suggested by Kapenda et al. (2001) with regard to the *aspects of task design*.

#### **4.5 Section E. Evaluation of the ~~final~~ version of the compact programme in terms of standard test item ~~construction~~ criteria**

##### **a. Evidence that the programme is relevant**

The practical tasks/activities are ~~based~~ on the general and physical science school syllabus and the everyday ~~experiences~~ of the participants. Thus the tasks involved are relevant to the teaching ~~that~~ takes place at South African Schools, as evidenced by the photocopied ~~comments~~ recorded by both students and staff in Appendix 4.

##### **b. Is the programme balanced?**

The compact programme used in ~~the~~ present study has been found to be unrepresentative in terms of the topics it covered. Since the programme had to be conducted during the classroom ~~periods~~ at institutions, the range of the topics had to be confined to 'mechanics', 'electricity' and 'optics', i.e. to only two out of 20 chapters of Brink and Jones (1985-2000) and two out of 13 chapters of Study and Master (1999-2001) 's Physical Science textbook.

##### **c. Evidence for the efficiency of the items**

The compact programme required ~~the~~ completion of 17 individual practical tasks in 20-25 minutes. Thus the compact programme can be considered efficient in terms of time.

##### **d. Evidence for the objectivity of the items**

During the early stages of phase 1 the compact programme involved some ambiguously worded tasks. However ~~these~~ items have been revised and refined repeatedly for objectivity until agreement was reached on all the intended right



answers. The tasks of the compact programme were mostly short-answers type such as only a numerical value, ticking relevant options etc.

**e. Evidence for the specificity of the answers to the items**

According to Ebel (1972:374) the experienced science/technology educators should agree among each other that a given answer is the correct one, whereas novice students (non-experts) should score close to the expected chance (guess) score, as recorded in Table 4.16.

#### **4.6 Chapter summary**

This chapter has been presented in five sections. The quantitative analysis of the practical items/activities has been presented, and the achievement data gathered from 340 participants have been analysed and compared according to various grouping criteria such as gender, English proficiency levels, participants' schools/institutions and their locations, etc.

The qualitative findings of the research, which comprise the responses of the participants to an open-ended question, have also been presented and possible emerging themes and trends have been drawn from these responses.

The relevance of the compact programme of practical tasks to various theories and classifications of science practical work have been laid out, as judged by experienced science and technology educators.

Finally, the compact programme as a whole has been appraised according to standard test item construction criteria such as relevance, balance, efficiency, objectivity and specificity.

## **CHAPTER 5**

### **DISCUSSION OF RESULTS AND FINDINGS**

In this chapter the findings of the research will be discussed. The results will be linked to those of other authors in field, and an attempt will be made to provide reasons and explanations for these findings. In the previous chapter the findings of this research were presented in two main sections. In this chapter the same sequence will be followed. The relevance of the theories involved in the previous chapter will also be discussed and suggestions will be made in order to develop and improve the theoretical basis of practical assessment in science.

Set out in chapter 1, pages 3-6, are the seven main purposes of this investigation. This chapter discusses whether each of these purposes, in turn, has been satisfactorily achieved in the light of the evidence, data and results which have been presented in chapter 4. At the same time it points out how the new findings uncovered in this study either confirm or extend previously existing knowledge in physics education.

**5.1 Purpose no.1:** To gather evidence to establish the extent to which the 13 process skills listed in the Revised National Curriculum Statement Draft (2001) are tested by the 17 practical activities in the compact programme.

The recent Revised National Curriculum Statement Draft (2001) emphasizes the importance of promoting scientific literacy among learners through developing science process skills and promoting the life-long learnership; and the evidence presented in the current investigation supports this proposed approach.

Adey (2001) examined some of the impacts of theory on the development of science curricula and the practice of science teaching. He criticised the process

skill movement in science education and argued that the process skills movement ignores the importance of content. Adey also argues that process without content is not possible.

The emphasis on content and process seems to precede the emphasis on the end product of learning. The Revised National Curriculum Statement Draft (2001) states that the learning area Natural Sciences has two major aims: to monitor the progress of learners (a process) and to facilitate learning so that they can reach their full potential. With the compact programme of practical activities educators may have more chance to observe and record the learners working and using their skills, which may make it easier for the educator to monitor the process of learning.

Bennett and Kennedy (2001) quoted the following recommendations by the National Council for Curriculum and Assessment (NCCA) in Ireland:-

- Practical work should be an integral part of the syllabus.
- All students should perform a set of mandatory experiments listed in the syllabus.
- Students should be given credit for practical work.
- There should be assessment of the practical work done by each student.
- The assessment should be valid, fair and impartial.
- The assessment should be externally monitored.
- The student's record of practical work carried out should be central to the assessment.
- The practical assessment should be worth 15% of the overall mark in the final examination.

There is evidence in the literature to suggest that practical work should be part of classroom activities and should be assessed. In the present study, the participants also expressed their enthusiasm and support for practical work and for support in science teaching (see page 34 of chapter 4). However the research in the field does not seem to be conclusive, especially with regard to specifying its nature and methods. At this point, the above listed recommendations have importance in Ireland because of the percentage of practical assessment

specified in the final examination. The compact programme has introduced the idea of using actual apparatus in the formal assessment of science learning, although this approach is not explicitly mentioned in the Revised National Curriculum Statement Draft (2001).

The judgments and opinions of the experienced science and technology educators and academics, regarding the relevance of the activities to the process skills, are listed and summarized in Table 3.1. These findings are now discussed in more detail for each item.

Activity 1 asked the participants to determine and measure the volume of an object with irregular shape. The participants had to hypothesize how to measure the volume. Then they needed to plan an investigation to do this and perform this investigation; and then they measured the volume by using a measuring cylinder. They recorded this information and they had to communicate this information on the answer sheet paying attention to the scientific unit notations.

The issue of unit notation is not specifically mentioned in the revised document.

Activity 2 asked the participants to identify one of the three shoes that applies the most pressure on the floor by observing the three shoes, comparing their surface areas, estimating the pressures they would apply, then using the theory of pressure and area.

Activity 3 required the participants to identify the North Pole of three differently-shaped magnets. They needed to refer the theories regarding magnetism and produce their own hypothesis on the method of identifying the North Poles. Then they needed to plan an investigation to evaluate this hypothesis by observing the behavior of the compass needle when magnets are brought closer (doing the investigation). Their observations needed to be

interpreted and the participants had to predict and confirm the North Pole of the magnets.

In item 4, the respondents were given two light bulbs (100W and 60W). In part A they were asked to indicate which of the two bulbs would cost less to use; and in part B they needed to select the one that would glow more brightly. To respond to this activity the participants needed to have observed light globes in streets, shops or at home. By interpreting the information provided about the bulbs they needed to propose a hypothesis to explain the relation between the power of the bulb and its cost and brightness. By referring to and interpreting their past observations and experiences with light globes they needed to sort and classify them according to their costs and brightness. Finally they needed to communicate this information on the answer sheet.

Item 5 asked the participants to estimate how many of 1 watt tiny bulbs would be sufficient to illuminate the inside of a normal refrigerator, which requires the participants to imagine and compare the size of a refrigerator and a room. The mean score of the overall sample on this item was 24% correct, within a reasonable margin of error, agreed upon by a panel of experienced physics teachers.

This low score could mean that they did not know how to approach the task because, during the pilot trials when the participants were given a delayed clue, then they could make an acceptable guess. Most participants verbally indicated that they never looked at the power of the bulb in a refrigerator. Most participants were aware of the power of an ordinary bulb used in a room, but they were unable to compare it with the refrigerator light globe – a higher order thinking skill to be carried out using a basic item of apparatus held in the hand.

In this item the participants first needed to ask themselves what the power of a refrigerator bulb is. By comparing the size of a room and size of a refrigerator

they needed to predict the power of the refrigerator bulb. They had to interpret this information and the information given in the task and estimate how many of these bulbs would be necessary for a refrigerator. They also needed to record this information and communicate it with the researchers by putting it on the answer sheet.

Item 6 asked the participants to identify one of the four different arrangements of cells that will light a bulb for the longest period. They first had to observe all four arrangements to identify and sort the types of connections. Then they needed to refer to their theoretical knowledge about the connections of cells, for example, in torches or alarm clocks, and interpret it for this particular case. They needed to be able to ask and answer what the effects of different connections of cells are on a circuit. Finally, they had to compare all three connections with each other and choose the correct one.

Item 7 included a circuit that involved two cells in series, three resistors each of 10 ohms and an ammeter to indicate when the circuit was completed and current existed in the circuit. Two resistors were connected in parallel to each other and they were connected to the third one in series. Therefore the participants had to analyse (observe) the circuit carefully to identify how the resistors were connected. Then they had to remember how to calculate the resistance of different combinations and connections of resistors theoretically and record this information for calculation. After performing calculations they expressed (communicating scientific information) the result with scientific unit notations.

Item 8 had three parts. Participants were given a series circuit that involved cells, two bulbs and an ammeter connected between the bulbs. The first part of the task asked the participants to indicate the direction of the conventional current, which required them to observe the circuit and identify the + and – poles of the battery. In the second part the participants measured the current

between the two bulbs using the ammeter, and then they had to communicate this value with its unit on the answer sheet. They had to remember or deduce the rule for the magnitude of the current in a series circuit (theory) and combine it with the present information and predict the magnitude of the current at a point on the circuit wire after the second bulb.

Item 9 involved three different types of mirrors (concave, convex and plane) and the participants were asked to identify each type of mirror. They simply had to hold and examine the mirrors (observe), compare them with each other, classify them according to their shape and put this information on the answer sheet (communicate).

Finally, item 10 presented two lenses (convex and concave) and asked the participants to identify the one that gives a real image. This required them observe the lenses, distinguish between concave and convex, remember and apply the theory, and interpret this information. They could also choose an experimental method by setting a hypothesis and designing an experiment using the theoretical background (real images can be cast on a screen), and then carrying out the experiment and interpreting the result.

The findings for the 17 activities were that 'observing' was the most relevant skill, and skills of 'using models and theories' and 'communicating science information' were also highly relevant, followed by the 'interpreting' skill. The compact programme did not include any open-ended tasks which would require the participants to design a new device, model or a system. Only the more basic skills were involved in the programme.

The compact programme emphasized additional process skills that are not directly specified in the Revised National Curriculum Statement Draft (2001:99-100), such as skills in expressing accurately the scientific notation of units, translating between mathematical formulas and text, comprehending

written information and instructional procedures, applying conceptual understanding to practical situations, visualizing, linking school science to everyday reality, etc.

**5.2 Purpose no.2:** To develop and discuss a practical programme of activities and items which meet the criteria for test item construction.

It can be very difficult to satisfy adequately and simultaneously all of the normative criteria for test item construction such as relevance, balance, efficiency, objectivity/freedom from ambiguity/clarity, specificity, control, task specification, directedness, fairness, validity, standard-based, difficulty, discrimination reliability and speededness. Especially when it is a practical activity, it is even more complicated.

Leonard and Penick (2000:360) pointed out that valid standard-based activities should engage the students in observing; asking and identifying questions and problems; identifying dependent and independent variables; formulating hypotheses; designing and conducting experiments; manipulating independent variables; collecting data; organizing data; displaying data; inferring from data; generalising; applying generalisations; communicating results; and formulating new hypotheses. They also argued that inquiry often makes learning more interesting and engaging, and it can have lasting effects on one's mind.

In the compact programme there were instances where this was the case. For example, activity 3B had an almost ideal difficulty but it failed completely to discriminate between high and low achievers. On the other hand, activities 1 and 9B had excellent discriminations but their difficulty indices were not close to ideal.

Activity 4 was agreed by experienced science educators to be clear, fair, valid, efficient and relevant, but this item had a low discriminating coefficient, a low



difficulty index and a low reliability coefficient. However it didn't affect negatively the overall reliability of the programme.

While trying to make a particular item specific, focused, efficient and clear from ambiguity other characteristics may have to be compromised.

**5.3 Purpose no.3:** To discuss the appropriateness of the Western Cape Education Department (WCED) Assessment Workbook criteria.

No specific data was gathered regarding the appropriateness of the criteria laid down in the WCED Assessment Workbook. However, no comment or indication of the irrelevance of the compact programme to these criteria was stated either. Perhaps the programme was not focused on the specific skill(s) or content knowledge. It may need to be revised to measure specific skill(s), then a more focused programme could be obtained.

The data collected reflected the variety of the sample groups, but the size of the sample could have been larger. Perhaps it could also have been more coherent.

Data gathered from tertiary level participants and educators tended to be more dependable and clear because they were more mature and serious about the tasks. In the case of secondary level participants, due to the negative attitude of some of the students towards science, a few might have been less careful and serious, for example, by handing in blank programme evaluation sheets.

Problematic for a classroom teacher could be the implementation and evaluation of the criteria suggested by WCED, i.e.: transparency, democratic, participatory, based on pre-determined criteria, variety of methods, learner-paced, flexibly expansive, criterion referenced, support for the learning process, diagnostic, enriches the fast learners, focused and addresses the needs of learners. One of the issues that the educators indicated in certain discussions

was their comprehension of these suggestions and criteria. They complained that the official documents are usually difficult to relate to their actual classroom practice. For example, the meaning of a science assessment test being “democratic, participatory and transparent” may not be very clear to the educators.

#### **5.4 Purpose no.4: How well does the programme meet the 35 Revised National Curriculum Statement Draft (2001: 4; 7; 10; 14-16) criteria?**

The present programme of practical tasks was evaluated against the 35 criteria for assessment advocated by Revised National Curriculum Statement Draft (2001). The experienced science educators agreed that the present compact programme satisfied the following criteria: learner-centeredness; activity-based; durable; promotes the application of scientific knowledge and understanding; encourages careful observation; fosters an appreciation of the relationships and responsibilities between science and society; enables prediction, verification and repetition; lays the basis for further studies in science; promotes understanding of science as a human activity; is culture-fair; promotes learners' effective use of visual, mathematical and language skills to communicate; enables learners to make sense of the world; is logical; is intuitive; is evidence-based; and promotes an understanding of cause and effect (Table 3.2).

When the overall programme is analysed it lacks the characteristics of peer assessment, open-endedness, promoting an understanding of the history of science, promoting an understanding of the relationship between science and other Learning Areas, and promoting an understanding of responsibility to ourselves, society and the environment. To design extension and enrichment options that would cover all these characteristics could be the next phase of development for the core activities of the programme.

Experienced school science teachers agreed that the compact programme is learner-centered, activity-based, durable, logical, promotes application of scientific knowledge and understanding, enables prediction, verification and repetition, requires careful observation, lays the basis for further research in science, promotes understanding of science as human activity, encourages girls to participate in science activities and culture fair. They also indicated that the following criteria were satisfied to a moderate degree: the programme promotes students' visual, mathematical, and language skills to communicate, is evidence-based, and enables learners to make sense of the world.

The practical activities of this compact programme therefore have the basis for further development for both teaching and assessment. The activities can be extended, refined and amended to use for various curriculum purposes.

**5.5 Purpose no.5:** To determine and discuss the programme performance scores of different groups of participants in different contexts at different levels of development.

Recent TIMMS results (Howie, 2001) revealed that South African students did not perform well on the questions relating to the real world situations. However, they performed better on the items that they could relate to everyday experiences. Although these two conclusions might seem to contradict each other, it may mean that South African students were not able to relate every real world situation to their own experiences and they were not familiar with wider applications of scientific knowledge and process. The findings of this present study are also in agreement with this argument because, for example, when the participants were asked to identify which of the two light globes (100W and 60W) would be cheaper to use and would be brighter, most of them replied correctly because they deal with light globes regularly. However when they needed to estimate the power of a refrigerator bulb by comparing the size of a room and a fridge, most of them failed to do so.

The mean score of the participants on the electricity items was 4.44 (out of 15). The identification of the conventional current in a series circuit was one of the challenges and a cause of alternative conceptions in electricity (Osborne, 1981; Jabin and Smith, 1994). Activity 8A asked the participants to indicate the direction of conventional current in a series circuit which consisted of a battery, two bulbs and an ammeter connected between the bulbs (Figure 3.8), but only 232 out of 340 participants could point to the correct direction. The nature and the direction were conceptual issues in the topic of electricity.

Another misconception in electricity is that some students tend to think that current gets weaker and weaker as it goes around the circuit and it gets used up (Shipstone, 1982; Jabin and Smith, 1994; Moodie, Bashe and Watson, 1995; Solomon, 1980). In the item 8 of this study, a series circuit (described above) was given to the participants. The participants were required to read the current (after the first bulb) from the ammeter and estimate the current at another point (after the second bulb) of the same circuit. 221 participants indicated that the magnitude of the current at that point was '0' which indicated that these participants assumed that the current is used up by the two bulbs and after the bulbs there were no more currents in the circuit.

Stanton (1989) argued that students tend to overgeneralise the situations that they experience and that they tend to apply them to all the related situations. As stated in chapter 2, electricity has many abstract notions, so learners may acquire alternative conceptions in this topic.

In the TIMSS-R results it is stated that a major emphasis is placed on knowing basic science facts and concepts. However South Africa places only a moderate emphasis on these aspects (Howie, 2001:39).

The mean total achievement score of the 340 sample participants was 11.08 (out of 25) in this research. An analysis of the achievement scores indicated that the participants could identify apparatus and could make basic measurements with the simple items of measuring instruments supplied. However, when the task required deeper conceptual understanding the participants had difficulty. For example, they could identify the concepts of 'convex' and 'concave' to an acceptable extent but, when they were asked about the types of images formed by convex and concave lenses, they produced very low scores.

In the TIMSS studies differences also occurred between the achievements of English first and second language students in South Africa. Especially when they needed to generate the answers themselves in English they achieved much lower scores because they appeared to lack deeper language skills.

The majority of South African students who took part in the TIMSS study did not speak English as their first language. One interesting finding of TIMSS research was that the students with either English or Afrikaans as a prime language performed better than the students who spoke other mother tongues. This may be due to the fact that such learners live mostly in rural areas where they do not necessarily converse in English. They use English only as the medium of learning at school which may not necessarily be enough to improve usage of English. Only 26% of the participants in TIMSS spoke English as their first language. In South Africa only 9% of the population comprises English first language speakers (Marsh and Shaw, 2001:240)

In this current research, it was also expected that differences would occur between the achievements of English first and second language participants. When mean total achievement scores are considered significant differences were observed. English first language participants outperformed English second language participants.

In order to explore a possible cause of this difference, it was decided to consider some other variables that may influence this. Therefore the responses of English second language participants were divided into two groups according to the geographical areas their schools are situated.

This analysis revealed a surprising result (see Table 4.11 for details). As might be expected, English second language participants at high schools situated in privileged areas achieved significantly higher scores than those who attend schools situated in unprivileged areas (townships). However, when these privileged English second language participants were compared with English first language participants, it was discovered that the English first language participants achieved only slightly higher than them, yielding no significant difference. This unexpected finding suggests that language proficiency levels of the participants is not the only factor that influences their achievement.

Level of the participants' English proficiency obviously had an impact on their achievement because the wordings of the practical items in this research were in English and the participants needed to comprehend what a particular task required. However, through a number of clarifying pilot trials this factor was minimized as much as possible.

Therefore, other explanations need to be considered. One possible reason for the underachievement may be a lack of resources, because one participant indicated that his/her school did not have the apparatus and equipment that were used in the practical tasks.

When the participating schools/institutions were compared the lowest achieving school was a high school situated in a township. The socio-economic status of participants from schools situated in more privileged areas was more favourable than those in townships. Therefore this has a direct impact on the schools' provision of equipment and the necessary facilities.

Another reason for underachievement may be the educator factor. It was also indicated in the TIMSS report (Howie, 2001:35) that 38% of the science teachers did not have formal qualifications in science. However, in this study this was not investigated except for informal discussions with teachers. Marsh and Shaw (2001:236) stated that many South African teachers are ill equipped, under-qualified and unprepared, especially in rural areas.

While being observed during their 50-minute sessions, the participants in the schools in underprivileged areas did not show a high level of self-confidence. They were usually hesitant to ask questions and handle the apparatus in the practical items.

Surprisingly, on activities 3B, 3C, 5, 8A, 9C and 10 English second language participants achieved higher mean scores than English first language speakers. The difference in the underachievement of English first language participants were significant on items 3B, 5, 8A and 9C. The underachievement of English first language participants on activity 3B will not be discussed here due to the low reliability of the task.

English second language participants achieved higher mean scores on items 5, 8A, 9C and 10. However these differences were not significant.

In order to reveal more information about the link between English proficiency and the achievement scores, the practical items may be divided into two groups; the items on which English first language participants achieved higher and the items on which English second language participants achieved higher. The average difficulties of the items in these two groups were calculated separately. It was observed that the items on which the English first language participants achieved higher scores had a 41,8% difficulty level and the other items had a 53,4% difficulty level. However it must be noted that items 3B and 5, on which

English second language speakers achieved higher scores, had low reliabilities. On item 10 English second language speakers achieved only slightly higher than English first language speakers but this item had a 75.5% difficulty level.

This may indicate that there are important factors other than English proficiency that influence the achievements of participants on a practical test. During the developmental stages of this test, practical items were administered with different sample groups, including Xhosa speaking students. One of the purposes of this was to eliminate as many extraneous factors as possible that may influence the achievements of the participants. Another purpose was to make the wording of the items as clear and understandable as possible to all of the participants so that the results could focus on the actual achievement of the participants rather than on other factors.

The level of English proficiency of the English second language participants who were at township schools appeared to be low, and this could be observed in the written comments they supplied. They also tended to use simple language in their comments, and basic grammatical and language errors were common.

The finding that the tertiary level participants achieved significantly higher than the secondary level participants is expected. The participants in the tertiary level institutions studied science in high school and, being older, they may have had more experience with the concepts and topics involved in the practical activities. Nine of these 32 tertiary level participants also had science degrees.

Participants in School 30, situated in an underprivileged area, achieved significantly below all the other schools. They were all Xhosa speaking students. Remembering the participants' English language proficiency levels and their achievements discussed above, this finding gives a clearer picture about the underachievement of certain groups of participants. Students from this particular school indicated that their school lacked the apparatus used in the



activities. During the visit to this school it was observed that the school's science store room did not have many items of equipment.

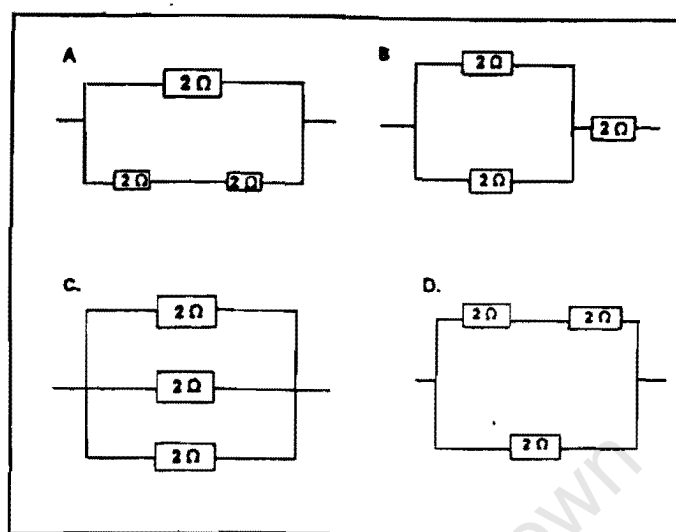
When the difficulty indices of the items are compared it is observed that the average difficulty level of the items that are directly involved in the matriculation syllabus was 28.5% (easy), but it was 45.7% (average difficulty) for the items not involved in the matriculation syllabus.

From these values of item difficulty levels, one would expect that the participants would achieve better results on the items which are involved in the matriculation syllabus because their average difficulty level was lower. The fact that these items are involved in the matriculation syllabus also supports this as well because it is expected that the educators put more emphasis on the items that are involved in the matriculation syllabus.

Thus one can conclude that whether or not some topics are involved in the matriculation syllabus did not affect the learners' achievement on these activities.

Question 1.15 in 1999 Standard Grade Physical Science Matriculation Examination paper in the Gauteng province focused on the same topic as item 7 of the compact programme. A copy of this question is reproduced in Table 5.1.

Table 5.1 Question 1.15 Three identical resistors each of  $2\ \Omega$  are connected to give a combined resistance of  $3\ \Omega$ . Which one of the following circuit diagrams illustrates how this was done?

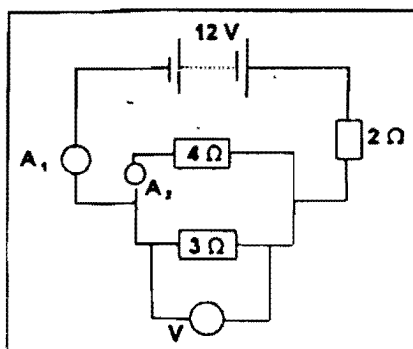


As it can be seen the examinations question is almost identical with the practical task item no. 7 of the compact programme. This item would help students understand the topic better if they studied it.

Question 9 of the same Physical Science Matriculation Examination paper also had a similar focus to item 8 of the compact programme. It is reproduced in Table 5.2.

Table 5.2 Question 9 of the 1999 SG Physical Science Matriculation paper

The internal resistance of the battery and ammeters is negligible in the following circuit.



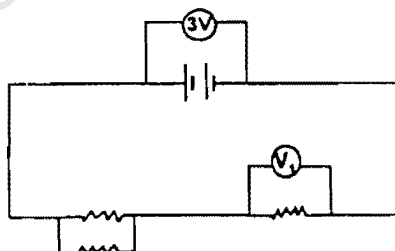
Calculate:

- 9.1 The total resistance of the circuit
- 9.2 The reading on ammeter  $A_1$
- 9.3 The reading on the voltmeter
- 9.4 The reading on ammeter  $A_2$

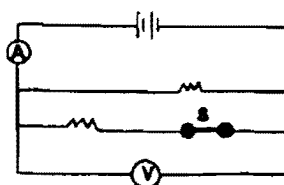
1999 Physical Science Higher Grade Examination paper 1 in the Free State province included the following questions:

Table 5.3 Questions from the 1999 Free State Higher Grade Physical Science Matriculation Examination paper 1

- 1 14 Three identical resistors are connected as shown in the diagram. The reading on the voltmeter across the cells is 3 V. What will the reading on  $V_1$  be?
- A. 3 V
  - B.  $2\frac{1}{2}$  V
  - C. 2 V
  - D.  $1\frac{1}{2}$  V



- 1 16 The resistance of the cells cannot be ignored. How will the readings on the ammeter and voltmeter be affected when switch S is closed? They will ...



- | Ammeter     | Voltmeter        |
|-------------|------------------|
| A. decrease | increase         |
| B. increase | decrease         |
| C. decrease | remain unchanged |
| D. increase | remain unchanged |

The apparatus used in the items forming the compact programme were chosen from among everyday ones. The results of this research revealed that, although they had a familiarity with the items, it did not have an enhancing impact on the performance scores of the participants. The overall degree of familiarity of the participants was rated 14.54 (out of 24) and overall mean score was 11.06 (out of 25). This may indicate that the context in which the participants handled or dealt with the apparatus was not necessarily scientific. Therefore, they may not have known about the scientific aspects of the everyday experiences.

One of the purposes of this research was to find out if there would be any significant correlation between the achievement of participants and their degree of familiarity with the apparatus used in the practical test items. It may be expected that the participants who were more familiar with the apparatus would achieve higher scores than the participants who were less familiar with the apparatus. However the analysis of the results did not agree with this. There were low correlations between the achievement scores of the participants and their degree of familiarity with the apparatus suggesting that whether or not they had handled these items of apparatus previously did not make significant differences to their achievement scores.

This finding suggests that, although the participants had handled the apparatus before, it did not necessarily improve their learning. It may also suggest that the ways in which they were exposed to these items of apparatus did not always achieve thorough learning. Therefore the ways in which science teaching and practical work are used is very important, because engaging a variety of methods and practical work in the classroom does not necessarily guarantee effective teaching. Some of the teachers at the schools that were visited stated that they would like to engage in practical work in order to show the learners the practical implications of science; but they said that they do not know where and how to start. Some of these teachers were at schools which were better equipped than most schools.

Chacko (1997:45) categorised practical work as 'Teacher Centered' and as 'Student Centered', and he prioritised twenty aims, as follows:

1. As a creative activity.
2. To make phenomena more real through experience.
3. To help remember facts and principles.
4. To practise seeing problems and seeking ways to solve them.
5. To indicate the industrial aspects of science.
6. To promote a logical reasoning method of thought.
7. To encourage accurate observation and description.
8. For finding facts and arriving at new principles.
9. To become able to comprehend and carry out instructions.
10. To elucidate theoretical work as an aid to comprehension.
11. To develop self-reliance.
12. To arouse and maintain interest.
13. To develop an ability to communicate.
14. To develop an ability to co-operate.
15. To develop certain disciplined attitudes.
16. To develop specific manipulative skills.
17. To verify facts and principles already taught.
18. To develop a critical attitude.
19. To give experience in standard techniques.
20. To prepare the students for practical examinations.

Among these aims, the aims numbered 2, 3, 9, 12, 16, 17 and 20 were deemed highly relevant to the current programme. In the tasks of this study, it was attempted to make the phenomena and concepts more real by showing the actual apparatus to the participants. It was observed from the participants' attitudes and comments that this kind of practice will help them remember the facts and principles better. They were required to make accurate observations and describe them in a meaningful way. The participants also had to be able to understand and follow certain instructions. It was observed that participants' interests were definitely raised and they maintained their concentration during the programme. The practical items required the participants to be able to manipulate the pieces of apparatus as well as identifying them. Most of the

participants had been taught the concepts and phenomena by their science teachers before this set of exercises, therefore they had an opportunity to check and verify certain facts and principles. This programme could also be used as a tool for preparation for other forms of practical examinations. One high school learner already stated his demand for practical tests in other subjects as well. .

The aims numbered 1, 4, 5, 6, 8, 10, 11, 13, 14, 15, 18 and 19 were deemed moderately relevant to the practical test items used in the present study. The participants had an opportunity to improving their logical reasoning, creativity, selected problem solving skills, skills of identifying sample industrial aspects of science, self reliance, communication skills (verbal and written), co-operating skills, self-discipline and experience in standard techniques in science. During the pilot stages of the research development the participants were allowed to work in groups and communicate their observations and opinions with each other.

Bennett and Kennedy (2001) reported the results of research which investigated the effectiveness of a new assessment model. It was developed by the National Council for Curriculum and Assessment (NCCA) in Ireland as a practical model which assessed manipulative skills, observational and measurement skills, recognition and understanding of apparatus and understanding of the experimental work.

The NCCA felt that the changes perceived by the teachers to be very radical would be less than effective because they would require too great a shift in practice. The committee also decided that a shift to continuous assessment of practical abilities by the teachers would not be feasible. Thus, for South Africa, limited or compact programmes of short practical activities might possible be one way ahead in the continuous assessment debate.

Solomon (2001:95) stated that half of the knowledge one learns at school becomes out of date by mid-life. Thus it is important to try to decide what to teach at school. She stated that usually facts (which may be demonstrated by practical work) last longer than the theories built on them. Therefore she suggested that we may focus on the facts (selected practical work) and discuss the interpretations of it with the students because the factual results of a well-conducted practical work activity would be more durable than their interpretation.

During the course of the current investigation, an important discovery was that the qualitative remarks made by various groups sometimes varied because each group looked at the item from a different angle. Students usually indicated if they enjoyed, liked, managed to complete, found an item easy/difficult while academics and teachers tended to focus on what the purpose of the item was and what skills and knowledge it measured as well as the items' academic utility (reliability, validity, discrimination etc). For example, for item 9 the students indicated that they found different types of mirrors interesting and exciting, whereas the academics indicated that the skills of identifying types of mirrors was a low level skill. One high school learner wrote, "Electricity items were difficult; I have forgotten what I have learnt in school". However the average difficulty of the eight electricity items was 42%. Thus the point of view of who make the comments is important.

More than one hundred positive and encouraging remarks regarding practical work and assessment were made by both academics and learners. They all agreed that the compact programme contributes to learning science.

**5.6 Purpose no.6:** To determine the usefulness, relevance of and enthusiasm for the programme by different interest groups.

Sutherland and Peckham (1998) reported that many students consider assessment to be a discriminatory process which identifies who fails and who passes. However, the recent research and policy documents emphasise that assessment should be used as an aid in effective teaching. According to the student comments reported in chapter 4, the learners admitted that they learnt during the sessions of this research, although this was an assessment programme of exploratory practical activities, not a formalized teaching activity.

The participants indicated very positive responses to the value of the instructional practice of the compact programme. The high school learners usually indicated that they enjoyed seeing the actual application of the theory that they learn. Some of them also indicated their thoughts and opinions on the usefulness and effectiveness of the programme. One emerging theme from the high school learners was that practical experience in science was a source of interest and motivation, probably because they feel that they deal with something real. One can argue that if an educator can use practical work properly it will definitely add some positiveness and variety to the classes. This may encourage effective learning and even more students to do science. Especially, students from disadvantaged backgrounds showed very positive attitudes towards the exercise because they do not have most of the equipment and, even if they do, they do not get a chance to use it. In the storeroom of the school science laboratory there were only a few items of equipment and from their condition it could be seen that they were not used recently.

From the high school students in underprivileged schools there was almost no negative comment. However, students attending schools situated in more developed areas would indicate if they did not like science or practical work in particular. This may be a reflection of the participants' level of self-confidence.



Teachers-in-training/practice and academics also indicated their support for the programme in terms of academic its value. Some of the teachers-in-training made the following comments: *"I can see the need for having hands-on experience"*; *"These activities can be linked to everyday life"*; *"I found electricity items difficult because of lack of knowledge"*. They tended to comment more on the academic value of the practice. There were incidences where the high school learners also commented about the value of the programme.

**5.7 Purpose no.7:** To determine and discuss a perceived relevant **match** or a perceived "irrelevant" **mismatch** between the science process skills tested by the current experimental programme of practical items and the descriptive theories of practical science and its classification schemes and criteria.

The practical tasks used in this study were classified by volunteer science teachers and academics according to different learning theories of science and assessment frameworks, and the theoretical criteria in science and science teaching and learning outcomes.

The details of these theories were presented in Chapter 4. Gardner's Multiple Intelligence theory, White's components of memory, Frans' components of thinking, Solomon's and Outcomes-Based Education's learning outcomes, criteria for practical tasks used by Kapenda et al., Race's suggested criteria for assessing practical work and Lock's assessment framework for practical skills were all used to classify the practical tasks.

## **Gardner's (1983) theory of "*Multiple Intelligence*"**

### **1. Linguistic Intelligence**

Linguistic intelligence is necessary for every person and individual in order to communicate with other people both in writing and verbal. In any assessment practice the participants should first comprehend the question or a task that is usually accompanied by a written text. Especially during phase 1 of this research *Linguistic Intelligence* was involved when the participants were asked to discuss and critique the practical items among each other and to comment on the items either verbally or in writing. During phase 2 the participants also needed to read the written instructions for each item and comprehend them before answering. The participants were also required to communicate science through proper use of vocabulary. Therefore if this kind of practice is utilized in science class it may contribute to the development of the learners' Linguistic Intelligence.

### **2. Logical-Mathematical Intelligence**

This kind of intelligence was involved in tasks 1, 2, 3, 4, 5, 7, 8 and 9, therefore the current practical items may be used to develop Logical-Mathematical Intelligence of science learners. With some revision and amendment of practical tasks this may be achieved much more effectively. For example, the learners may be given a related problem in future and they may be asked to work out the procedure and do the actual investigation (e.g. current at different points of a series circuit, etc.).

### **3. Spatial Intelligence**

Spatial intelligence was involved in items 1, 2, 5, 9 and 10. *Spatial Intelligence* involves thinking three-dimensionally. A person who acquires spatial intelligence can imagine and perceive a three-dimensional structure of objects. He/she can visualize the movements/rotations of objects in space. In general, spatial intelligence is involved in the current programme at a moderate level.

#### 4. Bodily-Kinesthetic Intelligence

In all of the practical items the participants were required to handle and work with different apparatus. Therefore this kind of intelligence has a very strong relation to the practical test items used in this study. Again the practical items may be used in different formats in order to achieve better outcomes, depending on the context and the aim the exercise (e.g. to let the students connect the ammeter; to let them connect the resistors to get different overall resistances; to ask students to make different connections of cells; to ask students to obtain a real image of the window and to show it to the class; etc.)

#### 5. Musical Intelligence

Musical Intelligence was found to be irrelevant to the current practical tasks.

#### 6. Interpersonal Intelligence.

As in the case of *Linguistic Intelligence*, *Interpersonal Intelligence* was also involved, especially during the pilot stages of this research.

#### 7. Intrapersonal Intelligence

In order to allow the development of *Intrapersonal Intelligence* the students in science class may be allowed to perform these practical tasks and may be required to compare their responses with the expected ones. In this way the students will be able to assess themselves as well, which is one of the emphases of Outcomes-Based Education.

*Musical Intelligence*, *Interpersonal* and *Intra-Personal Intelligences* have been identified to be irrelevant to phase 2 of the compact programme. Therefore these components are not considered when it is compared with other theories.

*Bodily-Kinesthetic Intelligence* was found to be the most relevant to the practical tasks in general. Since the compact programme involved practical

tasks instead of paper-and-pencil type tests, the participants were required to handle and use actual apparatus in most of the tasks. It was especially highly involved in tasks 1, 3, 6, 7, 8, 9 and 10. *Logical Mathematical Intelligence* also has a high relevance to the practical tasks because they needed logical reasoning in most cases.

### **Lock's (1989) assessment framework for practical work skills**

Lock used this assessment framework to study the relationship between the component skills. These practical skills have been utilized to classify the practical test items used in this study.

#### **1- Observation**

Items 1, 3, 7, 8, 9 and 10 have been found to be strongly relevant to this component skill of assessment. In these items the participants were required to be good observers of various everyday events and apparatus, and to make accurate measurements and conclusions.

#### **2- Manipulation**

Manipulation skills were involved in items 1, 3, 6, and 8. The participants did measurements, and had to use the apparatus accurately and systematically.

#### **3- Interpretation**

Interpretation skills were involved in items 2, 3, 4, 5, 6, 7, 8 and 10. With slight revisions other items could also be used to improve and measure interpretation skills.

#### **4- Planning**

Planning skills were involved mostly in item 1 where the participants were required to formulate a procedure to measure the volume of the given object.

### **5- Report**

For each of the practical items the participants were required to report their findings on the response sheet provided. In a different set up of a lesson the participants could also be asked to report their responses verbally, during the pilot stages of the research.

### **6- Self-reliance**

During the administration of this research it was not always possible to allow the participants to ask for assistance, but during the pilot stages this was done successfully. The participants had an opportunity to seek help and discuss their responses.

Observation was the skill most relevant to the compact programme. There were real instances in the tasks and the participants needed to observe them first before they could respond correctly. They observed the apparatus, objects and sometimes combination of these actual apparatus.

Observation skill was followed by interpretation and manipulation skills.

**Solomon's (1998) theory of the multiple contents of the public understanding of science**

- 1- Science for the Personal Development of the Individual
- 2- Science as a Requirement for a Specific Profession or Vocational Board/Body
- 3- Science for its own Rational Development
- 4- The Humanistic Utility of Science

Solomon's theoretical components are all moderately relevant to the compact programme. Solomon's components are more wide and general so may not have been related directly to the compact programme. They focus on more general aims and on the importance of the public understanding of science.

### White's (1988) elements of memory

#### 1- Strings

The *Strings* component of memory has been found to be relevant to items 2, 3, 4, 6, 7, 8, 9 and 10. For example, "North pole attracts South pole"; "The magnitude of current is the same at every point of a series circuit"; etc.

#### 2- Propositions

Items 2, 3, 4, 6, 7, 8, 9 and 10 have been identified as involving *propositions* components of memory, such as  $V = I \times R$ ,  $P = \frac{F}{A}$ ,  $P$  (power) =  $V \times I$ , etc.

#### 3- Images

*Images* are involved in items 4, 5, 6, 9 and 10. The participants were required to imagine the size of a refrigerator, and the bulb used in a room, the power and brightness of bulbs, etc.

#### 4- Episodes

*Episodes* are involved in items 2, 3, 4, 9 and 10. Participants could recall the times when they tried to burn a piece of paper by using a magnifying glass under sunlight.

#### 5- Intellectual Skills

*Intellectual skills* are involved in all of the items various extents. The participants were required to know how to read instruments together with interpreting the scaling on the measuring instrument. In most cases they were also required to apply the knowledge they had learnt in theory to actual practical apparatus questions.

## 6- Motor Skills

*Motor skills* were involved strongly in items 1, 3, 6, 7, 8, 9, and 10. The participants were required to handle, use and make measurements with the actual apparatus provided. They needed to acquire certain motor skills in order to identify and use the apparatus properly.

## 7- Cognitive Strategies

*Cognitive strategies* were found to be relevant to all of the practical test items in this study.

The *Motor skills* component of White's theory was the most relevant among the components, followed by Intellectual Skills and Propositions.

In other theories the components emphasizing the hands-on abilities were also highly relevant to the programme because of the nature of the tasks. Some tasks involved mathematical relations and formulas as well, so the *propositions* components were also highly relevant.

### **The Revised National Curriculum Statement Draft's learning outcomes of Natural Sciences Learning Area: -**

1. The learner is able to develop and use science process skills in a variety of settings.
2. The learner is able to develop and apply scientific knowledge and understanding.
3. The learner is able to gain an appreciation of the relationship and responsibilities between science and society.

The practical test items of this study have been found to be strongly relevant to these three learning outcomes. In the practical items the participants were required to acquire and use science process skills, apply these skills to the

practical tasks and observe the practical aspects of scientific knowledge used in their everyday lives. As stated by most participants, they were impressed and they enjoyed seeing that the scientific knowledge that they learn at school has its applications in real life situations. This helps the participants to gain an appreciation of science and its relation with and implications for social life.

#### **Franus' (1992) components of thinking**

Cognitive and technical thinking skills have been identified as being strongly relevant to the current practical test items. Literary thinking skills were involved mostly during phase 1 of the research. As in the case of Linguistic Intelligence of Gardner, the practical items may be revised and amended for the development of Literary thinking skills. However, in this practical test the participants still had to comprehend written instructions which required language skills. Therefore it was not completely ignored.

#### **The relevance of the various criteria for practical tasks used by Kapenda et al. (2001)**

The investigation of the relevance of these criteria revealed an interesting result. The criteria regarding the aspect design of practical tasks were found to be one of the least relevant classification schemes, but the criteria regarding the context of the tasks were found to be highly relevant. This may imply that the design of the tasks should be reviewed again. However it may also be argued that these criteria, as worded, cannot be considered together and compared with others because among them were criteria that were contrary to each other such as "inductive-deductive" and "open-closed". When the criteria are examined in terms of the student involvement, they are found to have a high level of student involvement.



In terms of the contexts of the tasks the practical programme was found to be efficient in terms of both activity duration and student recording time.

Among all the classification schemes Lock's assessment framework for practical skills was found to be the most relevant of all. This assessment framework was specifically prepared for assessing practical skills. Lock (1989) found skills of *planning* and *interpretation* strongly related to each other. In this research also these skills were equally relevant to the compact practical programme. However their relevance to tasks 1, 4, 8 and 10 varied.

Kapenda et al.'s criteria regarding the aspects of task design were the least relevant but, as explained earlier it, may not be appropriate to compare this theory with others. Among the rest of the schemes, Solomon's theory of multiple dimensions of public understanding of science was the least relevant together with the reduced relevance of Fransus' components of thinking. These theories did not have high relevance most probably because they were too wide for the present practice. The compact programme may form (be relevant to) part of them but do not cover the whole theory.

### 5.8 Purpose no.8: Recommendations for teaching practical physics

Leonard and Penick (2000:359) reported that two important recommendations of the National Education Standards in the USA, were that students learn and practice the methods of science (science process skills) and develop an understanding of the nature of science (empirical, objective, verifiable, tentative etc.). It is important for the students to be familiar with the fundamentals of the scientific process and enquiry such as the apparatus used, basic facts and principles and basic skills. The programme of this study measured the achievement levels of the participants for these skills, knowledge, facts and principles.

They stated that the new vision gave more emphasis to cognitive skills than observing, inferring, classifying, forming hypotheses etc. They also stated that students should learn science through inquiry process i.e. doing science rather than hearing about science. Modeling of how scientists learn is an important part of science education.

They studied an activity suggested by the National Education Standards that promoted the development of process skills and understanding of nature of science.

Leonard and Penick (2000:359-360) pointed out that standard-based activities should engage the students in observing; asking and identifying questions and problems; identifying dependent and independent variables; formulating hypotheses; designing and conducting experiments; manipulating independent variables; collecting data; organizing data; displaying data; inferring from data; generalising; applying generalisations; communicating results; and formulating new hypotheses. In the compact programme the participants did not have to have all of these skills such as asking and identifying questions, identifying and manipulating independent variables.

Leonard and Penick (2000) argued that inquiry makes learning more interesting and engaging and it can have lasting effects on one's mind.

Lawson (2000:641) stated that American Association for Advancement of Science recommended "science should be taught as it is practiced". In the South African context this is a very challenging issue because the educators themselves also do not seem to be qualified enough to practice this and the resources are also not satisfactory. However, this could be achieved through designing and conducting simpler activities which do not require too many complicated and technical tools and apparatus.

Lawson (2000:641) presented the results of a survey that revealed the problems that inexperienced teaching assistants encountered in an inquiry-based (activity-based) laboratory medium. These problems included the following: -

- Some students do not participate enough,
- Some students do not know how to get the inquiry started,
- Some students do not care and do not see the inquiry as relevant to their lives,
- Some students do not listen,
- Some students lack background knowledge,
- Some students talk at inappropriate times,
- Some students have bad attitudes and are disruptive,
- Some students are doing poorly and want extra credit,
- Some students do not want to think for themselves,
- Some students socialise during lab,
- Some students participate too much,
- Some students do not clean up after themselves,
- Some students cheat and plagiarise the others' work,
- Some students are tardy and leave early.

It is very likely that these problems are being experienced in South African schools. The concentration, participation, negative attitudes and lack of confidence of the learners are common issues in a standard classroom. Therefore his suggestions are important to note for the South African context.

He suggested possible methods of dealing with these issues. His suggestions included the following:

- Keep the groups as small as possible (two people are ideal).
- Specify the duration of the task.
- Monitor students while they are busy with a task.
- Give them "to-be-graded" assignment to complete during the sessions.
- Give them clear and complete introductory remark.
- Objectives of the activity should be very clear.
- Make the tasks challenging.
- Point to the aspects of the task indirectly related to everyday life.
- Get them 'do' first then 'talk'.

He concluded that it takes considerable practice to develop needed skills for an inquiry classroom, but once the skills are acquired the inquiry classroom becomes a very exiting and rewarding place. It may be argued that the compact programme satisfied most of these suggestion such as the desirable size of the

group (during phase 1 this was one of the conclusions); the duration of the tasks; “to-be-graded’ assignments (the programme was an assessment programme); relevance of the tasks to everyday life, etc.

The participants showed a very high level of interest towards the practical programme. It implies that a programme of this nature definitely has a positive impact on the learners’ attitude and their learning. Therefore the compact programme of practical activities may be used as part of everyday classroom activities with necessary amendments.

**5.9 Purpose no.9:** To discuss more deeply and thoroughly how physics practical work should be assessed.

Much of the previous research into the attainment of science process skills and scientific and technological literacy has involved paper-and-pencil type of research instruments. Lawrenz, Huffman and Welch (2001) studied the achievement of different subgroups on four different assessment formats, namely, multiple-choice test, written open-ended test, hands-on lab skills test and hands-on full investigation. They reported that high achiever students seemed to be doing equally well on different assessment formats. However, for low achiever students the assessment format mattered more. They concluded for this result that different assessment formats measure different competencies. They stated that hands-on tests could provide different information about the achievement of different subgroups, and the results of this study in Cape Town support this claim.

Bennett and Kennedy (2001:104) stated that a written examination of practical work can assess only a limited number of areas of the cognitive domain, namely knowledge, comprehension and application. They argued that some key areas of practical work such as analysis and synthesis could not be assessed by written examinations at all.

Race (1997:18) argued that many areas of study involve practical work, but it is often much more difficult to assess such work in its own right. Assessing reports of practical work may involve measuring the quality of the end product of the practical work but not the work itself. He laid out some suggestions for assessing practical work. The involvement and relevance of these aims were discussed by a panel of four science educators and their consensus discussions are presented next to each aim: -

- Reserve some marks for the process: This has been done by the researcher.
- Get students to self-assess how well they undertook tasks: This was done in some items (item 3 and 8) to some extent.
- Ask students to include in their reports “ways I could do the experiment better next time”: This was done verbally by the researcher during phase 1, and the students used the comment sheet, Figure 3.12, to record their suggestions for improving the activities.
- Include some ‘supplementary questions’: Not done in the compact programme.
- Design the right end-products: The panel of educators agreed that the end-products were designed satisfactorily.

There is a wide range of agreement regarding the value of the practical work in science (Bennett and Kennedy, 2001). However the assessment of practical work and the knowledge and skills of practical work has not been researched conclusively. This might be due to the difficult nature of designing the right practical assessment tools. Bennett and Kennedy (2001) noted very positive responses from the students to a new assessment model for practical work which assessed manipulative skills, observational and measurement skills, recognition of apparatus and understanding of experimental work. They argued that there is a need for changes to be made in the assessment procedures in

order to give a more valid and fairer assessment of students' ability at practical work.

It is also important to set the tasks in such a way that they include a wide range of skills and every learner (participant) can demonstrate his/her abilities. Otherwise it would be unfair to conduct the tasks on those participants who do not have the included skills but acquire other skills.

Race (1997:37) pointed to the danger of measuring the final product of certain skills and ignoring measurement of the skills themselves. He laid out ten questions and suggested that addressing these questions may help to get the balance right. These questions consisted of the following:

- 1- What exactly are the practical skills we wish to assess?
- 2- Why do we need to measure practical skills?
- 3- Where is the best place to measure these skills?
- 4- When is the best time to measure these skills?
- 5- Who is in the best position to measure practical skills?
- 6- Is it necessary to establish minimum acceptable standards?
- 7- How much should practical skills count for?
- 8- May student self-assessment of practical skills be worth using?
- 9- May student peer-assessment of practical skills be worth using?
- 10- Is it necessary to have a practical examination?

The compact programme of practical activities of the present study was not designed to answer these questions, but the evidence gathered may lead to the discussion of questions 2, 3, 4, 5, 8 and 10. The practical skills involved in science teaching, in general, may be applied to other areas of daily life such as solving practical problems. Thus measuring these skills should constitute an important of science teaching to assess whether or not these skills are being mastered by the learners. The time and place of measuring these skills may depend on the educator. Because depending on the educator it may be measured during formal teaching, in laboratory, during an excursion, etc. This may be done before, during or after teaching, depending on the purpose of the assessment. Measuring practical skills may be done by the teacher or an outside

examiner again depending on the purpose. However it is advisable that a summative assessment of these skills is conducted by an outside examiner. The effectiveness of student self-assessment of practical skills may need to be researched in more detail. The assessment strategies that are listed in the Revised National Curriculum Statement Draft (2001) include student self-assessment and peer assessment as possible strategies. As pointed out earlier written examinations lack the ability to measure certain skills. Therefore, a well-set and conducted practical examination may be much more effective in practical assessment.

Visser (2000) suggested three strategies for conducting practical work and their assessment:

1. Stations involving a number of different experiments; a series of practical tasks in the same subject in the form of follow up. Each one is constructed on the data gathered from previous one.
2. Predict, explore and explain (PEE) where a well-chosen question is discussed among students; a well-constructed practical question is chosen and the learners discuss it until they reach a consensus. This question usually departs from a knowledge that the learner already has.
3. Strategies with the teachers' and students' own design and execution: the learners are given an open-ended research question and they need to design an experiment to investigate the problem. This strategy consists of three phases i.e. planning phase, implementing phase and concluding phase.

In the compact programme of practical activities these three methods may be observed to various extents. For example, each task may be considered as a station where follow up tasks or some prerequisite tasks can be designed and implemented all together. For this purpose a number of items/tasks from the

same topic should be developed. For example, identification of different types of mirrors may be a starting task and the next task may be to specify daily use for each one and another follow up item may be to design a simple device that can be used in daily life.

The item 8 of this programme may be an example of a PEE. The item did not require the participants to verify their guess on the current at a specific point of the circuit, but this could be done in different contexts. The third strategy of Visser (2000) was not practiced extensively in this programme. Because it requires more time and designing experiments, conducting them and drawing conclusions from the results.

Each one of the three strategies suggested by Visser (2000) has its strengths with slight differences in their focus. The first one 'stations' promotes conducting a specific experiment by students which develops and measures certain skills. In PEE usually the students can be given a narrower task and they are required to predict the result and then perform the investigation and explain the obtained results. This also involves skills that should be developed through science practical work. The last suggestion of Visser reminds one of following an enquiry method in conducting investigations where hypotheses should be identified, the investigations should be designed, and the hypotheses should be tested and revised if necessary. Depending on the purpose of the practice any of these three strategies could be used in a science classroom. It may be a better strategy to start with the first strategy with a particular group, before moving to the others, because the first strategy involves more introductory and basic skills and knowledge.

Buchan (1992:19) stated that, following the first examination after the introduction of a new syllabus in the United Kingdom, there were two main innovations in the examination system: firstly, the need to operate within nationally defined criteria and, secondly, to assess practical skills. Buchan



(1992) studied the published schemes of internal assessment of practical skills offered by five English and Welsh examining groups and identified five key aspects of variation between these schemes:

1. The percentage given to practical skills.
2. Skills and abilities assessed and their grouping.
3. The definition of scoring of levels of performance.
4. The number of assessments to be made and their relationships to the marks submitted.
5. The suggested approach.

The variation mentioned above may be the case for South Africa as well if the criteria, standards and skills and abilities are not specified nationwide. The present study involved measuring certain practical skills. The programme used a scoring system out of 25 marks. The educators at the schools need to be given more specific directions and suggestions to have a standard level of science education.

She emphasized that variation between schemes will influence the science teaching through the differing emphases on assessed work.

One of the most important issues in assessment (if not the most important) is to identify the purpose of the assessment, i.e. diagnostic, formative, summative, etc. After deciding on the purpose and context of the assessment the focus knowledge and skills to be included in the assessment should be clarified. Only then will it be appropriate to decide on the strategy, because each strategy has its strong focus on certain skills. This is very much dependent on the educator personally. A well-equipped educator would be able come up with many different approaches to measure one skill.

It is stated earlier that a practical assessment task programme should focus on a wide range of skills and knowledge in order for it to be fair. Therefore all three strategies advocated by Visser (2000) should be used at different occasions of

teaching because it is very difficult that one activity or strategy can measure all the necessary skills.

### **5.1 Purpose no.10: Evidence disclosing weaknesses in the research design of the dissertation**

Although the practical tasks of the compact programme underwent various pilot trials, there are still possible improvements for the individual tasks and for the programme as a whole. Especially the skills and content knowledge included in the compact programme could have been organized better. The tasks with low reliability could be refined and improved.

For some items there were different comments. For example, some participants indicated specifically that they enjoyed the electricity item while there were other participants who found the items too difficult.

The variety of the sample groups that took part in the study is also another issue about the research design. Although the study involved sample groups from a variety of backgrounds, the size of each sample could be larger and the conclusions of the study would be more appropriate and valid. Also, the sizes of the samples of educators and academics could be larger, and more time was needed for these sessions. These sessions were usually conducted at conferences and workshops where usually a limited time is allocated (30-60 minutes). A more detailed analysis requires more time and longer discussions, especially on the classification of the tasks according to different classification schemes.

The participants were given an open-ended question to express their ideas. For the same purpose the participants could be given a list of possible views and asked to rate them, as well as an open-ended one.

More graded skills could be involved in a programme of this nature. Some of the activities measured lower level skills (e.g. identifying the bulb that would cost less or glow brighter, identification of different types of mirrors etc.) while others involved moderately complex skills and knowledge (e.g. measuring volume and identifying poles of magnets) and higher order skills and content knowledge (e.g. calculation of resistance and obtaining real image with lenses). Visser's (2000) "stations" strategy is a good example of this nature. It starts with a relatively simple question and builds on it.

### Chapter Summary

This chapter discussed the results and findings of the research that were presented in Chapter 4. The relevant process skills that were measured/encouraged by the compact programme were elucidated. Also the compact programme was examined according to the criteria of test item construction and WCED Assessment Workbook and National Curriculum Statement Draft criteria.

Examples from past Matriculation papers were presented and compared to similar items in the compact programme. The participants' attitudes and written comments on the programme were also analysed and discussed. This chapter discussed in detail the perceived relevance and match/mismatch between the activities of the programme and various classification schemes. Issues around teaching and assessment of practical work in school science were amplified as well. Finally the chapter examined the weaknesses in the research design of the study.

## CHAPTER 6

### CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

This chapter presents the conclusions, possible implications and recommendations of the research. The investigation was designed to answer various questions listed in chapter 1. Consequently this chapter will be organized around the same themes and focus questions.

**6.1 Question 1:** Which of the 13 process skills listed in the Revised National Curriculum Statement Draft (2001:99-100) are tested/encouraged by the practical items in the compact programme?

#### Conclusion

The data produced in this study supports the consensus conclusion that the compact programme of practical activities encouraged the use of the following scientific skills: -

- Process skill 1. **Observing and comparing:** these skills were encouraged strongly in all of the items.
- Process skill 2. **Measuring and estimating:** encouraged strongly in items 1, 2, 5 and 8; moderately in items 3, 4, 6 and 7; weakly or not at all on items 9 and 10.
- Process skill 3. **Recording information:** encouraged strongly on items 1, 5 and 7; moderately on items 3, 8 and 10; weakly or not at all on items 2, 4, 5, 6, 9 and 10.
- Process skill 4. **Sorting and classifying:** encouraged strongly on items 4, 6 and 9, moderately on items 3 and 10; weakly or not at all on items 1, 2, 5, 7 and 8.
- Process skill 5. **Interpreting information:** encouraged strongly on items 3, 4, 5, 6 and 10; encouraged moderately on items 2, 7 and 8; weakly or not at all on items 1 and 9.

- Process skill 6. **Predicting what will happen if something changes:** encouraged on items 3, 5 and 8; moderately on items 4, 6 and 7; weakly or not at all on items 1, 2, 9 and 10.
- Process skill 7. **Hypothesizing:** encouraged strongly on items 1, 3, 4, 8 and 10, moderately on items 2, 5 and 6; weakly or not at all on items 7 and 9.
- Process skill 8. **Using models and theories:** encouraged strongly on items 2, 3, 6, 7, 8 and 10; moderately on items 4, 5 and 9; weakly or not at all on item 1.
- Process skill 9. **Raising questions about a situation:** encouraged strongly on items 5 and 6; weakly or not at all on the other items.
- Process skill 10. **Planning an investigation:** encouraged strongly on items 1, 3 and 10; moderately on items 4, 5, 6 and 8; weakly or not at all on items 2, 7 and 9.
- Process skill 11. **Doing the investigation:** encouraged strongly on items 1, 3 and 10; moderately on items 4, 5, 6 and 8; weakly or not at all on items 2, 7 and 9.
- Process skill 12. **Communicating science information:** encouraged strongly on items 1, 4, 5, 7, 8 and 9; moderately on items 2, 3, 6 and 10.
- Process skill 13. **Design, make and improve a device or system to solve a practical problem:** this skill was not encouraged by any of the items of the programme.

The analysis of the relevance of the skills to the current programme revealed that **observation skills, using models and theories and communicating science information** were involved in almost all of the items. The participants also recorded an awareness of the importance these skills. The participants also identified handling, touching and experiencing the actual apparatus to be of high importance.

### Implications

The data presented in Table 3.1 (process skills encouraged/measured by the compact programme) implies that **observation** is one of the most important skills in the compact practical programme. **Using models and theories** may also be an important part of this type of science teaching because by referring to theories and models learners may make better sense of the world. **Experiencing** the actual apparatus by the learners is also favoured by the learners.

These findings imply that each one of the practical items is able to encourage and measure some of these process skills. Especially items 1, 3, 5, 8 and 10 encouraged and measured at least six of these skills. Therefore these items may be able to provide learning materials which are in harmony with the science process skills proposed in the latest curriculum document.

Another implication is that in the near future some of the important items such as items 2, 6, 7, 8, 9 and 10 might be developed hierarchically with additional components being created to incorporate the testing of more sophisticated process skills. The programme mostly encouraged the practice of simpler and less sophisticated skills and did not involve higher order skills such as making and improving a device or system to solve a practical problem. The above-mentioned items may now be revised and elaborated to encourage this skill. For example, learners might now be asked to design and assemble a telescope, a microscope or a periscope with various mirrors, lenses and prisms. Item 6, which asked the participants to indicate which one of the four different arrangements of cells would last longest, may be developed by asking the participants to design a battery for a more sophisticated device. They may also be asked to design a shoe to walk on a track with a hard surface, or on sand or snow.

### **Recommendations for teacher training**

Science educators are required to be able to comprehend and interpret the policy document, and also to know what each skill requires, because they will be expected to implement it in classrooms when it is finalized. Therefore, the requirements and explanations of these skills should be included in teacher training programmes.

**6.2 Question 2:** Do the practical items deployed in this study contain additional worthwhile process skills that are not in the Revised National Curriculum Statement Draft (2001:99-100)

### **Conclusion**

Certain skills not specifically mentioned in the Revised Curriculum Statement Draft (2001) were identified, such as (1) expressing scientific notation of units accurately, (2) translating mathematical formulas/expressions into meaningful texts, (3) accurately comprehending written information and instructional procedures, (4) applying conceptual understanding to practical situations, and (5) visualizing and linking school science content to everyday reality.

The learners also showed an awareness of certain science process skills not mentioned in the new Draft Document, such as recalling and remembering scientific information, answering questions and describing their applications in everyday experiences, etc.

### **Implications**

The implication of these findings may be that these newly identified skills (1) to (5) ought to be considered for inclusion on pages 99-100 of the Revised National Curriculum Statement Draft, and the list of suggested skills provided might be expanded to include these additional skills.

**Recommendations for learners**

The learners might be guided to perform activities in which they can develop these additional skills, as well as those suggested by the new Draft Document. The practical tasks investigated in this compact programme may be used for this purpose.

**Recommendations for educators**

In order to develop these skills in school learners the science educators may use, in their science classes, the practical tasks either as they are or by revising them (as explained earlier) to include more sophisticated skills. If so, the educators should also be provided with appropriate resources and guidelines to perform these activities.

**Recommendations for the curriculum development**

The additional skills that this compact programme encouraged could be added to the 13 skills suggested by new Draft document.

**Recommendations for teacher-training**

These additional skills could be incorporated into the didactics of teacher training programmes so that future science teachers can be made aware of these skills.

**Recommendations for in-service training**

Some practising teachers may not have acquired these skills or the techniques and methods of instructing or implementing these skills. Therefore, selected teachers who are currently in schools might undergo in-service training, when the additional skills may be discussed with them.

**6.3 Question 3:** After repeated phase 1 field trials to improve the presentation of the apparatus, wording, content and process tasks incorporated into each individual practical item, (and also incorporated into the performance



programme as a whole in its final form), do the ten items also meet the following standard criteria for test item construction advocated by Ebel (1972: 359-360) and by Marshall and Hales (1971:165)? (a) Relevance, (b) balance, (c) efficiency, (d) objectivity/freedom from ambiguity/clarity, (e) specificity, (f) difficulty, (g) discrimination, (h) reliability, (i) fairness, (j) speededness, (k) control, (l) directedness, (m) task specification, (n) validity and (o) standard-based.

### **Conclusion**

Experienced science educators evaluated the compact programme of this investigation. The compact programme was agreed to be relevant, efficient, objective, valid, specific and fair. However, it is not completely satisfactory in terms of balance, difficulty, reliability and discrimination. The programme included examples from only certain chapters of the school science syllabus, indicating that it was not well-balanced.

In terms of difficulty and discrimination, the compact programme included some items which failed to discriminate between high and low achievers, and which did not have acceptable difficulty levels, such as activities 1, 3B, 4 and 9B.

The overall outcome of the present investigation may be considered as generally satisfactory. Although it has aspects which need to be improved, reliability is a well-known problem when attempting to establish consistency in practical task responses.

### **Implication**

The findings imply that the development of a programme of practical activities can be complicated in terms of attempting to satisfy all the desirable criteria of test item construction. While trying to optimize the attainment of one criterion, some other criteria may be compromised.

Another implication is that the format and context of a practical activity should remain amenable to revision and improvement.

### **Recommendations for improvement of the activities**

Although the overall programme was found to be satisfactory, it has aspects that need to be amended. For example, activities 1, 3B, 4 and 9B could be re-designed for better difficulty and discrimination.

### **Recommendations for development of the compact programme as a whole**

More activities from other chapters of school science should be trialled and added to the compact programme.

- 6.4 Question 4:** Do the practical tasks satisfy the following additional criteria advocated by the Western Cape Education Department (WCED) Assessment Workbook (May 2001:4) and by the Revised National Curriculum Statement Draft (2001:73)? (a) Transparency, (b) democratic, (c) participatory, (d) based on pre-determined criteria, (e) variety of methods, (f) learner-paced, (g) flexibly expansive, (h) criterion referenced, (i) support the learning process, (j) diagnostic, (k) enriches the fast learners, (l) focused and (m) addresses the needs of learners

### **Conclusion**

The participants did not specifically examine the programme's relevance to the WCED Assessment Workbook criteria. However an analysis of the practical tasks according to these criteria may reveal that the programme had its strengths and weaknesses in the context of WCED Assessment Workbook criteria. Although the participants did not rank or indicate the relevance and appropriateness of the programme to WCED criteria, no comment or indication of the irrelevance of the compact programme to these criteria was stated either. It may be argued that perhaps the programme was not focused on the specific

skill(s) or content knowledge but the participants indicated in their written and verbal comments that the programme can support the learning process.

### **Implications**

One implication of the analysis of the criteria is that classroom teachers might have difficulty in implementing and evaluating certain undefined criteria suggested by the WCED, e.g.: “transparency, democratic, participatory, based on pre-determined criteria, variety of methods, flexibly expansive”, etc. For example, the meaning of a science assessment test/activity being “democratic, participatory and transparent” may not be very clear to the educators, and may be difficult to measure unambiguously.

### **Recommendations for analysis of these criteria**

The WCED criteria have not been investigated conclusively in this investigation. Therefore, further study and analysis of these criteria and their contexts may be needed with larger sample groups, once the WCED supplies operationalised definitions of these terms.

### **Recommendations for the official/policy documents**

The criteria presented may need to be explained further to the educators who are responsible for implementing them.

**6.5 Question 5:** During the eleven phase 1 field trials to improve the apparatus, wording, content and process tasks incorporated into each individual practical item, and into the performance programme as a whole in its final form, does the programme of task items also meet the 37 curriculum criteria advocated by the Revised National Curriculum Statement Draft (2001: 4; 7; 10; 14-16), such as:

- (a) Learner-centeredness
- (b) Activity-based

- (c) Promotes learners' effective use of visual, mathematical and language skills to communicate
- (d) Enables the learners to understand that the world is a set of related systems
- (e) Evidence-based
- (f) Enables prediction, verification and repetition
- (g) Encourages science as a social process
- (h) Requires careful observation
- (i) Promotes an understanding of cause and effect
- (j) Is culture-fair;  
and so on?

### Conclusions

The findings suggested that the following criteria were satisfied strongly by the programme as a whole:

Learner-centeredness; activity-based; durable; logical; enables prediction; verification and repetition; promotes the application of scientific knowledge and understanding; requires careful observation; lays the basis for further studies in science; promotes an understanding of science as a human activity; encourages girls to participate in the science activities; and is culture-fair.

The programme was adjusted by consensus to meet the following criteria at a moderate level:

Promotes learners' effective use of visual; mathematical and language skills to communicate; enables learners to make sense of the world; evidence-based; fosters an appreciation of the relationships and responsibilities between science and society; promotes an understanding of cause and effect; and is intuitive.

The following criteria were met weakly or not at all:

Promotes the use of creative and/or critical thinking skills to identify and solve problems; enables learners to organise and manage activities responsibly and effectively; promotes the collection, analysis, organisation and critical evaluation of information by learners; enables learners to use science and technology effectively; showing responsibility to the environments and health of others; enables the learners to understand that the world is a set of related

systems; encourages science as a social process; encourages the search for pattern; answers questions about the nature of the world; prepares learners for economic activity and self-expression; acknowledges the existence of 'alternative ideas' of the world by children and adults, which they bring to the world of the classroom; enables validation through peer view; involves an open contest of ideas; promotes an understanding of the history of science; promotes an understanding of the relationship between science and other learning areas; promotes an understanding of the contribution of science to social justice and societal development; promotes an understanding of responsibility to ourselves, society and the environment; promotes an understanding of the consequences that involves ethical issues; and is open to new theories and knowledge.

### **Implications**

One of the implications of these findings is that the compact programme tended to satisfy the basic curriculum criteria advocated by Revised National Curriculum Statement Draft, e.g. learner-centered, activity-based, durable and requiring careful observation. However, it does not adequately cover the more sophisticated criteria such as promoting an understanding of the contribution of science to social justice and societal development; promoting an understanding of the consequences that involves ethical issues; promoting an understanding of the history of science, etc., so, if desirable, the next task may be to develop new items along these lines.

Another implication is that these more sophisticated criteria may be problematic for a science educator when attempting to develop new activities.

### **Recommendations for the development of practical activities**

The activities may be revised, or completely new activities might need to be developed to meet these criteria, because these criteria are very comprehensive and it may not be possible to meet them by one type of activity alone.

### **Recommendation for the investigation**

The types of activities, and the contexts in which these criteria may be satisfied adequately, should be investigated and new activities may be developed according to those findings.

## **6.6 Achievements of the sample groups of participants**

### **Conclusion**

The quantitative findings of this investigation were classified into various categories for statistical comparisons of the achievement scores of the participants; for example: the participants' gender, English language proficiency, academic levels, grade levels, schools/institutions, degree of familiarity with the apparatus used in the activities and the practical tasks' inclusion in the matriculation syllabus.

The statistical analysis of the data produced in this research revealed significant results in relation to the participants' English proficiency levels, the schools/institutions of participants; and their academic levels. However no significantly different achievements were recorded in regard to gender and the learners' degree of familiarity with the apparatus used in this research.

English first language participants achieved significantly higher scores than English second language participants. English second language participants at schools situated in underprivileged areas achieved much lower scores than English second language participants from the schools in more privileged areas. Significant differences between the achievement scores of secondary and tertiary level participants were recorded. Tertiary level participants scored significantly higher than secondary level participants.

The achievement scores of male and female participants were not significantly different. Another surprising result was that the degree of familiarity of the

participants with the apparatus was not significantly related to achievement scores.

### **Implications**

One of the implications of the quantitative results is that it revealed that the language factor was an important variable with the particular samples investigated. However, it was also observed that it was not the only one. The school that the participants attend or the geographical area where it is situated was also important. This might have several implications. One is that the schools situated in underprivileged areas may be failing to use, or may be lacking, necessary resources and qualified educators. Another implication could be that the participants who attend the schools in privileged areas have more opportunity to improve their English proficiency levels because they have more opportunity to converse in English.

Tertiary level participants performed better overall than secondary level participants. This may imply that people learn about these concepts and remember them during the course of their life as they develop certain skills; or that they had more favorable opportunities to learn in the past. However, on some of the items their performances were comparable. This implies that certain skills and concepts may be obtained relatively more easily and then stay in one's mind.

The previous familiarity or unfamiliarity of the participants with apparatus did not have a measurable effect on their achievement. This might imply that the contexts in which they deal with objects may be different from the school science context, although it would be incorrect to try to generalize from the results produced in this very limited study.

**Recommendations for school development**

The schools should be supplied with resources necessary to develop science process skills. These may include human resources such as qualified teachers, because the literature review has shown that South African schools are experiencing a shortage of qualified teachers, especially in the field of science.

**Recommendations for classroom science teaching**

Teachers should encourage activities through which learners can develop science process skills, as well as their theoretical or conceptual understanding.

**Recommendations for teacher training**

If future science educators are well trained in these skills, they should be better able to develop the necessary process skills in their learners when they teach.

Another recommendation for teacher training may be that the science educators should be specially trained how to overcome or reduce the language barrier in science teaching.

**6.7 Classification frameworks****Conclusion**

The relevance of the compact programme to various theories and classification frameworks has been investigated in this study. The results showed that, although some of the frameworks were found to be more relevant than others, the compact programme did not cover any of the frameworks and theories completely. However, Lock's assessment framework for the assessment of practical skills was identified to be the most relevant of all.

**Implications**

The finding that none of the theories was entirely covered may imply that the theories and classification frameworks are very broad, since most of them were designed to cover the purposes, types or methods of science teaching and



science practical work. It may be very challenging to develop a full programme of practical tasks to cover all the categories of a broad framework.

### **Conclusion**

In order to develop a new framework for this type of practice, the theories presented in the previous chapter have been analyzed carefully and the following science process skills have been identified to be relevant to the current practice.

#### **(a) Comprehension skills**

It is important for a participant to be able to comprehend a practical task and its requirements. The participants should be able to understand the written instructions provided with the task item. This has links with Gardner's *linguistic intelligence* and Franus' *literary thinking*.

#### **(b) Recognizing given items of apparatus**

The participants should be familiar with the apparatus and recognize the name and the uses. This category may also involve the recognition of scientific aspects of everyday apparatus and devices. This skill has not been clearly identified in other frameworks.

#### **(c) Following instructions**

The participants should be able to follow instructions (written or verbal) to complete a task. The instructions may be either specific ones such as the procedure of an experiment, or more general such as open-ended investigations. This was related to Lock's *interpretation* and *self-reliance skills*.

#### **(d) Carrying out tasks and handling science apparatus**

They should be able to follow and perform a set procedure and use certain items of apparatus to perform necessary investigations such as measuring instruments.

These tasks can be open-ended, as well as ones in which a learner should be able to plan and carry out investigations. This skill was also mentioned in Gardner's *bodily-kinesthetic intelligence*, Lock's *manipulation skills*, White's *motor skills* and first and second learning outcomes of Outcomes-Based Education.

**(e) Observation skills**

The participants need to be able to observe the actual practical task and the emphasized variables. A participant should be able to identify which variables are to be manipulated in an investigation and which one should be kept constant. This is related to Lock's *observation skills*.

**(f) Interpretation of the observations**

Participants need to be able to interpret what they observe during the administration of a task. Putting together the evidence from an experiment, and drawing conclusions from that, are important aspects of this skill. This is closely related to Gardner's *logical-mathematical intelligence* White's *cognitive strategies*, and Lock's *interpretation skills*.

**(g) Making predictions**

After interpreting their observations the participants should be able to make predictions regarding further steps of a task. In other words, they need to be able to answer "what if ...?" and "what do you expect to happen after .....?" types of questions. This skill has been emphasized in Gardner's *logical mathematical intelligence*, Lock's *interpretation skills* and White's *cognitive strategies*.

**(h) Reporting and communicating scientific information**

The participants who have reporting skills can provide their responses in a desired manner. They pay attention to unit notations, expressing these details in a scientific way. This skill is important for a practical task because the

participants should be able to record and report their responses so that they can make accurate conclusions. Unit notations are not specifically emphasized in other classification frameworks used in the present study. However, this was emphasized in Lock's framework as *reporting skill*.

## 6.8 Further research

This section presents recommendation for further research in the field:

**Recommendation 1.** The size of the participants sample should be larger. If this compact programme was administrated to larger groups of participants more conclusive results could be recorded.

**Recommendation 2.** The compact programme encouraged certain process skills. However, the results of the investigation in relation to these skills are not always conclusive. Therefore a more comprehensive research is needed to investigate the process skills that are encouraged by practical activities.

**Recommendation 3.** Another possible research area is the context of developing these skills. Ways and techniques of developing these skills in more diverse contexts should be researched.

**Recommendation 4.** More demanding activities with graded skills may be developed and administered with participating students, teachers, teachers-in-training, etc.

**Recommendation 5.** The data gathered in relation to the attributes of the participants, e.g. the degree of familiarity should be collected more consistently in order to draw more reliable conclusions.

**Recommendation 6.** The evidence supporting theories and classification frameworks of science practical work should be examined in more detail. This may lead to a more comprehensive classification framework.

**Recommendation 7.** More diverse methods of conducting and assessing science practicals may also be another possible research area.

## 6.9 Final conclusion

One of the most important aspects of this research was that it introduced the idea of having a manageable programme of actual syllabus-based apparatus for assessing curriculum-prescribed science process skills. This research has investigated some of the current issues around science practical work. The research had its weaknesses as well as its strong aspects. It could be argued that the present investigation has made appreciable progress in identifying some of the most important issues, through the production and interpretation of its documented evidence from reality. However, further research is needed into the issues that this investigation has raised.

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# APPENDIX

## 1

Photocopies of published papers and  
articles in various journals and conference  
proceedings

## LIST OF PUBLICATIONS

- 1- Inal, A (2001). Theorien zum praktischen verstandnis auf dem gebiet der Physik und Technologie in einem entwicklungsland die entwicklung und klassifizierung von testverfahren betreffend. International Global Journal of Engineering Education,5 (3), 327-334.
- 2- Inal, A., Rochford, K. and Abrahams, E. (1999). Practical scientific literacy – the development, validation and classification of practical test items in Physics and Biology. Proceedings of the National Subject Didactics Learning Area Symposium, Cape Town, University of Stellenbosch, Smit, M.J. and Jordaan, A.S. (Ed.), 51-52.
- 3- Abrahams, E. Rochford, K. and Inal, A. (2000). The development, evaluation and implementation of practical assessment items in Physics and Biology for Curriculum 2005. Proceedings of the Science and Technology Education Conference, Cape Town, Cape Town College of Education, 4-7.
- 4- Inal, A. and Rochford, K. (2000). The construction, development and classification of test items in practical scientific literacy in Physics and Biology. Proceedings of the 8th Annual conference of the Southern African Association for Research in Mathematics and Science Education, Port Elizabeth, University of Port Elizabeth, 204-209.
- 5- Abrahams, E. and Inal, A. (2001). Labelling the structures of anatomical specimen and simple physical science apparatus as a form of language teaching: a report on a study involving 560 high school biology and physics students. Proceedings of the Conference on Integrating Content and Language: Providing Access to Knowledge Through Language, Cape Town, Peninsula Technikon. (<http://www.pentech.ac.za/pil88/abstract2.htm>).
- 6- Inal, A. (1999). Practical Scientific Literacy: The construction, development, and classification of sample test items in physics. Seminar Series: Pursuit of Excellence in Science and Mathematics Education, 3(1 and 2), 8-16.



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## Contents

Z.J. Pudlowski	229	Editorial
N. Grünwald	231	Guest Editorial
U. Seidel und E-G. Thoms	233	Vorwort
D. Schott und N. Grünwald	235	Gottlob-Frege-Zentrum und Reform der Mathematikausbildung
J. Cleve und U. Lämmel	245	Gottlob Frege - Logik und Grundlagenausbildung
M. Berger und A. Schwenk	251	Mathematische Grundfertigkeiten der Studienanfänger der Technischen Fachhochschule Berlin und der Schüler der Bertha-von-Suttner-OG Berlin
N. Kalus	259	Computational Science and Engineering (CE) - Eine Neue Eigenständige Disziplin für Postgraduale Masterstudiengänge
W. Nehrlich	265	Computeralgebra in der Diskreten Mathematik
T. Risse	271	Interaktive Mathematik-Skripte - eine Spielart Aktivierender Lehrformen
L. Teschke	277	Probleme der Mathematikausbildung an Hochschulen für Angewandte Wissenschaften
R-P. Tiedt	283	Unterstützung der Mathematikausbildung für Ingenieure durch Nutzung von Matlab
T. Schramm	289	Computeralgebrasysteme als Integrationswerkzeuge im Mathematisch-naturwissenschaftlichen Unterricht. Das Mathematische Pendel - Eine Fallstudie
D. Hannemann	299	Virtuelle Hochschule
J.R.J. Schirra	311	Motivationsanreize zum Erwerb Kommunikativer Kompetenzen: Eine Fallstudie in der Informatik
U. Klein, K-J. Peschges, E. Reindel und N. Grünwald	319	Anforderungen an eine Veränderte Ingenieurausbildung zur Besseren Lösung von Zukunftsproblemen durch die Absolventen Technisch Orientierter Hochschulen
A. Inal	327	Theorien zum Praktischen Verständnis auf dem Gebiet der Physik und Technologie in einem Entwicklungsland die Entwicklung und Klassifizierung von Testverfahren Betreffend
N.P. Puchkov	335	Die Hauptaufgaben der Mathematischen Ausbildung des Zukünftigen Ingenieurs und Pädagogische Probleme des Mathematikunterrichts in der Technischen Hochschule
K. Steinmüller	341	Technologien der Zukunft - Nutzen und Grenzen der Technikvorausschau

# Theorien zum Praktischen Verständnis auf dem Gebiet der Physik und Technologie in einem Entwicklungsland die Entwicklung und Klassifizierung von Testverfahren Betreffend

Aydin Inal

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Diese Studie beschreibt die Entwicklung, Klassifikation und Bewertung von 34 praktischen Tests bezüglich des technischen und physikalischen Verstehens. Unter Verwendung dieser Tests soll der Stand des anwendungsbereiten wissenschaftlich und technischen Verständnisses von unterschiedlichen, historisch benachteiligten Zielgruppen (Studenten und Lehrer im Bereich Wissenschaft und Technik) erfaßt und sowohl qualitativ als auch quantitativ verglichen werden. Dabei spielen der aktuelle Kontext und die geografische Region eine entscheidende Rolle. Die Herleitung und Klassifizierung der von erfahrenen Dozenten, Lehrern und Akademikern speziell entwickelten praktischen und technischen Tests bilden einen grundlegenden Teil dieser Studie. Das Ziel ist die Übereinstimmung einer Gruppe von erfahrenen Wissenschaftlern auf dem Gebiet der Lehre in Wissenschaft und Technik dahingehend zu bewerten, inwieweit die 34 Testverfahren den 6 verschiedenen Kategorien nach Gardner, White, Solomon, Lock, Franus und der Ergebnisorientierten Ausbildung (OBE) für das Lernen entsprechen. Dabei sollen speziell die Charakteristiken, Eigenschaften und das technische Design der Geräte mit den damit verbundenen manipulativen Fertigkeiten verglichen werden.

## ZIEL DER UNTERSUCHUNG

Eines der Hauptziele dieser Untersuchung besteht darin, die Entwicklung und die Bestätigung praktischer Testversuche von grundlegenden technologischen und physikalischen Fähigkeiten zu beschreiben, zu illustrieren und zu demonstrieren. Diese Versuche sollen dazu verwendet werden, um das fundamentale Verständnis für Elemente ausgewählter Themen in Physik und Technologie zu testen. Dabei soll der aktuelle Versuchsaufbau einer reinen *Papier und Bleistift* - Diagnose vorgezogen werden. Die Versuche sind anwenderfreundlich für ein allgemeines Publikum und für Studenten konzipiert und basieren dabei auf einem in sich konsistenten Rahmen der ausbildenden Didaktik.

Eine sich anschließende Langzeitstudie ist darauf gerichtet, die grundlegenden darstellenden Fertigkeiten, bzw. das Niveau der praktischen wissenschaftlichen und technologischen Fähigkeiten von einer vielfältigen Auswahl an Hochschulstudenten der physikalischen und technologischen Fachrichtungen zu untersuchen und zu

vergleichen. Dabei soll auch der Bedeutung verschiedener zusätzlicher Parameter, wie Geschlecht, Muttersprache, geografische Herkunft nachgegangen werden.

Das Hauptziel (s.o.) dieser Untersuchung besteht nicht nur darin Tests zu entwickeln, sondern auch ihre einheitliche Klassifizierung entsprechend den Kategorien von Solomon, White, Gardner, Lock, Franus und Ergebnisorientierten Ausbildung (OBE) zu ermöglichen [1-7].

Ein zweites Ziel ist die Untersuchung der Möglichkeit, die vielfältige Intelligenz der Zielgruppen, speziell auf dem Gebiet der praktischen wissenschaftlichen und technologischen Fähigkeiten, weiter zu entwickeln. Dabei kommt dem besonderen Umfeld in Südafrika und anderen Entwicklungsländern eine besondere Bedeutung zu.

## BEDEUTUNG DER UNTERSUCHUNG

Zwischen den wissenschaftlich- technischen Fähigkeiten des Einzelnen und dem Entwicklungsstand



einer Gesellschaft besteht ein enger und progressiver Zusammenhang. Die Entwicklung einer Gesellschaft erfordert Menschen mit wissenschaftlich-technischen Kenntnissen. Entsprechend dem Arbeitspapier des Bildungsministeriums der Republik Südafrika, sind Lernende aufgefordert zu demonstrieren, daß sie technische Prozesse, die bei der Lösung von Problemen und für die Befriedigung von Bedürfnissen erforderlich sind, verstehen. Dieses Papier hebt außerdem die Bedeutung hervor, die das Verständnis für den Einfluß von Wissenschaft und Technik auf das soziale Leben der Menschen, auf die Ökonomie und die Entwicklung einer Gesellschaft hat [7].

Wald stellt fest, daß in Ländern wie Israel und Irland, die gegenwärtig ein starkes Wachstum des Nettosozialproduktes (pro Person) erfahren, eine ebenfalls starke Nachfrage nach Ingenieuren besteht. Er erläutert weiterhin, daß die Verfügbarkeit von fähigen und gut ausgebildeten Mitarbeitern das High-Tech Investment fördert. Aus seinen Beobachtungen schließt er weiterhin, daß ein Mangel an fähigem technischen Personal droht [8]. Desweiteren weist er auf die Bedeutung dessen hin, was die UNESCO als *Trend zu höheren Anforderungen an direkte Erfahrungen von Schülern und ihre aktive Einbeziehung in den Lernprozeß durch Ermittlung und Entdeckung* bezeichnet und die Anwendung von Wissenschaft während der Einbeziehung von technologischen Elementen [9].

Lernende treten den akademischen Wissenschaften erstmals in der Primär- und Sekundarstufe der Schule gegenüber, das macht die Lehre in Wissenschaft und Technik an den Schulen so wichtig. Einige der grundlegenden Prinzipien und Ideen müssen in der Schule gelehrt werden, besonders auf dem Gebiet der sich schnell entwickelnden Technologie. Dies impliziert, daß eine neue Herangehensweise an den Stundenplan der Primär- und Sekundärstufe erforderlich ist. Nach der Herausstellung dieser Punkte führt Pudlowski neue Programmstrukturen ein und wählt Kernprogramme in unterschiedlichen Lehrplänen für Lehre in den Ingenieurwissenschaften aus, mit besonderem Schwerpunkt auf selbst durchzuführende Experimente [10].

Viele Problemstellungen müssen in Südafrika überdacht, modifiziert und verändert und einige schnelle Lösungen umgesetzt werden, um den Anforderungen der neuen Ära gerecht zu werden in der sich Wissenschaft und Technik schnell entwickeln. Demzufolge sind in der Lehrerausbildung und der Lehre in den wissenschaftlichen Fächern an den Schulen verschiedene wichtige Veränderungen und Ansätze erforderlich. Entsprechend Kahn muß jede technologische Entwicklung auf wissenschaftlicher

Mathematik und Technologieausbildung beruhen. Er stellt außerdem die Tatsache heraus, daß der Lehrplan auch das wissenschaftliche und mathematische Verständnis der Technik in unserem täglichen Leben beinhalten sollte, wie beispielsweise:

- Rehydration
- Anschließen eines 3-Pin Steckers an einen Wasserkocher
- Jumpstarten eines Autos
- die Art und Weise der Luft- und Wasserverschmutzung
- Risikoabschätzung und Finanzplanung.

Kahn hebt weiterhin hervor, daß eine Ausbildung in Wissenschaft und Technik eine besondere Rolle bei der Entwicklung eines Landes spielen und als Maß für dessen Entwicklungsstand gewertet werden kann. Demzufolge ist es erforderlich, daß speziell ausgebildete Lehrer mit modernen Lehrmethoden an den Schulen verfügbar sind, um die Ausbildung in Wissenschaft und Technik zu verbessern [11].

## HINTERGRUND DER UNTERSUCHUNG

Es besteht ein profundes Interesse an Untersuchungen zu den wissenschaftlichen Fähigkeiten von Studenten ebenso wie in der allgemeinen Bevölkerung.

## THEORETISCHE GRUNDLAGEN

In dieser Studie wurde das Niveau jedes Tests und der praktischen, technischen oder manipulativen Fertigkeiten entsprechend verschiedener Kategorien der Bildungswissenschaften auf dem Gebiet von Wissenschaft und Technologie klassifiziert.

### Gardner

Gardner entwickelte die Theorie der multiplen Intelligenz, die von einem einfachen numerischen Intelligenzquotienten Abstand nimmt. Gardner's Theorie zufolge können verschiedene Komponenten der Intelligenz getrennt betrachtet werden, welche bei einer Einzelperson durchaus unterschiedlich entwickelt sein können [1]. Gardner unterteilt das menschliche Potential und beschreibt die menschlichen Fähigkeiten durch 7 unterschiedliche Formen der Intelligenz, die im nachfolgendem mit dem Buchstaben *G* für Gardner gekennzeichnet werden.

- Linguistic Intelligence (*G ling*)  
*Sprachliche Intelligenz*
- Logical-Mathematical Intelligence (*G lm*)  
*Logisch-Mathematische Intelligenz*



- Spatial Intelligence (G spat)  
*Räumliche Intelligenz*
- Bodily-Kinesthetic Intelligence (G bk)  
*Körperlich-Kinästhetische Intelligenz*
- Musical Intelligence (G mus)  
*Musische Intelligenz*
- Interpersonal Intelligence (G inter)
- Intrapersonal Intelligence (G intra)

Die im Verlauf dieser Studie gewonnenen Daten zeigen eine deutlich erkennbare Betonung der logisch-mathematischen und körperlich-kinästhetischen Intelligenz (G lm, G bk).

### White

White definiert sieben verschiedene Elemente für das Gedächtnis [2], um den Lernprozess in Wissenschaft und Technik zu beschreiben. Diese werden im Folgenden mit *W* bezeichnet.

- Strings, (W string)  
*Zeichenfolgen/Zeichenketten*
- Propositions, (W prop)  
*(Lehr)sätze/Aussagen*
- Images, (W Im)  
*Bilder*
- Episodes, (W epi)  
*Episoden*
- Intellectual Skills, (W int)  
*Intellektuelle Fertigkeiten*
- Motor Skills, (W mot)  
*Motorische Fertigkeiten*
- Cognitive Strategies, (W cog)  
*Kognitive Strategien*

Die im Verlauf dieser Studie gewonnenen Daten sind auf die Elemente *W String*, *W Int* und *W Mot* fokussiert.

### Solomon

Solomon beschreibt eine umfassende Theorie des allgemeinen Verständnisses von der Wissenschaft [3]. In ihrer Arbeit *The Development of Life Skills through Science and Technology Education for the 21<sup>st</sup> Century* geht Solomon mit ihren Betrachtungen weiter als die von Schulen verwendeten Lehrpläne für wissenschaftlich-praktische Arbeit. Unter anderem hebt sie die größere Bedeutung der Wissenschaft im täglichen Leben und für soziale Belange hervor. Sie verschiebt den Kontext des Lernens in das häusliche Umfeld, sie verbindet Ökonomie und Wissenschaft und hebt den Zusammenhang zwischen dem Lernen einer Wissenschaft und der Beschäftigung von ausgebildetem Personal auf dem

Arbeitsmarkt, bzw. sprachlichen und grundlegenden Kommunikationsfähigkeiten. Dies ist erforderlich, um die Schüler auf eine berufliche Laufbahn zu lenken, die von der Industrie in ihrer Vielfalt von linguistischen und kulturellen Traditionen benötigt werden. Nicht zuletzt konzentriert sie sich auf die Bedeutung der Wissenschaft für die Entwicklung des einzelnen Schülers, die das Wachstum unabhängiger Lernfähigkeiten, z.B. Kreativität und Neugier, fördert.

In dieser Untersuchung werden die von Solomon vorgeschlagenen Kategorien mit *S* gekennzeichnet und folgendermaßen spezifiziert:

- Science for the Personal Development of the Individual (SI)  
*Wissenschaft für die Persönliche Entwicklung des Einzelnen*
  - by enhancing his/her life skills (SI life)  
*durch Förderung seiner/ihrer Lebensfähigkeiten*
  - by enhancing his/her vocational skills (SI voc)  
*beruflichen Fertigkeiten*
  - by enhancing his/her communication skills (SI com)  
*kommunikativen Fertigkeiten*
  - by enhancing his/her citizenship skills (SI cit)  
*Fertigkeiten als Bürger*
  - by enhancing his/her long-term values (SI val)  
*langfristigen Werten*
  - by enhancing his/her personal growth, feelings and emotions (SI grow)
  - by enhancing his/her personal growth, feelings and emotions (SI grow)  
*persönlichen Entwicklung und Gefühle*
- Science as a Requirement of a Specific Profession or Vocational Board/Body (SP)  
*Wissenschaft als Erfordernis eines besonderen Berufes oder einer beruflichen Institution/Körperschaft*
- Science for its own Rational Development (SR)  
*Wissenschaft für die eigene rationale Entwicklung*
  - as a logically structured set of concepts, theories, processes, skills, evidence, knowledge and limitations (SR con)  
*als eine logisch strukturierte Reihe von Konzepten, Theorien, Fertigkeiten, Prozessen, Beweisen/Aussagen, Erkenntnis und Grenzen*
  - as a development of historical events (SR hist)  
*als eine Entwicklung historischer Ereignisse*

- The Humanistic Utility of Science (SH)

*Der humanistische Nutzen der Wissenschaft*

- for societies' needs (SH soc)  
*für gesellschaftliche Bedürfnisse*
- for the economic development of a nation (SHE) with a specific reference to  
*für die wirtschaftliche Entwicklung einer Nation unter besonderer Bezugnahme auf*
  - i. better health (SHE health)  
*bessere Gesundheit*
  - ii. the environment (SHE envir)  
*die Umwelt*
  - iii. social reconstruction (SHE recon)  
*sozialen Wiederaufbau*
  - iv. science for the work place (SHE work)  
*die Wissenschaft für den Arbeitsplatz*
  - v. ethical dilemmas (SHE ethic)  
*ethische Dilemmata*
  - vi. the international future competitive edge (SHE compet)  
*die internationale zukünftige Wettbewerbsfrage*
  - vii. mobilization for informed, motivated and substantive social change (SHE change)  
*die Mobilisierung für einen informierten, motivierten und bedeutenden sozialen Wandel*
  - viii. cultural transmission of knowledge (SHE cult)  
*kulturelle Übermittlung von Wissen*
  - ix. adaptable, novel retraining of the workforce (SHE retrain)  
*eine anpassungsfähige, neue und erneute Schulung der Arbeitskräfte*

Im Rahmen dieser Untersuchung wurden die von Solomon eingeführten Kategorien genutzt, um Cluster bzw. Gruppen von praktischen Tests in einem vorgegebenen Themenbereich der Technik und Physik zu bezeichnen. Dies wird ermöglicht, da Solomons Kategorien umfassender und allgemeiner gehalten sind als die eher eingeschränkten Kategorien von White, Gardner, Lock und Franus. Demzufolge können sie dazu herangezogen werden, um Tests als Ganzes zu charakterisieren und sind auch auf jedes einzelne Teil innerhalb eines Test anwendbar.

### Lock

Ein weiterer Bewertungsmaßstab für die praktischen Fertigkeiten, die von Schülern der Sekundarstufe

(11-18 Jahre) erwartet werden können, wurde von Lock eingeführt. Ein Komitee von zehn erfahrenen Lehrern in wissenschaftlichen Fächern hat diesen Bewertungsmaßstab für Lock bestätigt. Er verwendet diesen Maßstab um die Beziehung zwischen verschiedenen Fertigkeiten bei der praktischen Arbeit zu untersuchen [4][5]. Dabei handelt es sich um folgende:

- Observation (L obs)  
*Beobachtung*
  - Observe accurately (with correspondence between the record and the event, as seen by a supervisor)  
*Genau beobachten (Übereinstimmung von Bericht und Ereignis, aus Sicht des Leiters/Betreuers)*
  - Read instruments correctly  
*Genau lesen der Instrumente*
- Manipulation (L man)  
*Manipulation*
  - Set up apparatus appropriately  
*Korrekt Aufbau der Apparatur*
  - Use apparatus/materials appropriately  
*Korrekte Verwendung der Apparatur/des Materials*
  - Work accurately/systematically with hands/fingers  
*Genaues/systematisches Arbeiten mit Händen/Fingern*
  - Carry out operations in correct sequence/follow instructions  
*Die Arbeitsschritte in exakter Reihenfolge durchführen/Anweisungen befolgen*
- Interpretation (L int)  
*Interpretation*
  - Interpret observations  
*Beobachtungen deuten*
  - Interpret numerical data/diagrams  
*Numerische Daten/Diagramme interpretieren*
  - Indicate sources of errors (in material and in methods)  
*Fehler anzeigen (des Materials und der Methoden)*
  - Ability to calculate  
*Fähigkeit zu berechnen*
  - Make predictions  
*Voraussagen machen*
- Planning (L plan)  
*Planen*

- Devise a simple experimental procedure (including selection of apparatus, measuring instruments)  
*Eine einfache experimentelle Vorgehensweise ausdenken (einschließlich der Auswahl der Apparatur und der Meßinstrumente)*
- Use of controls/trial experiments/observations  
*Verwendung von Kontrollen/probeweisen Experimenten/Beobachtungen*
- Problem-solving  
*Problemlösung*
- Report (L report)  
*Bericht*
  - Use scientific language (written/verbal)  
*Verwendung wissenschaftlicher Sprache (schriftlich/verbal)*
  - Arrange/organise the data/observations  
*Anordnung/Organisieren der Daten/Beobachtungen*
  - Accuracy with which the procedure is reported  
*Genauigkeit/Exaktheit mit der über die Vorgehensweise berichtet wird*
- Self-reliance (L self)  
*Selbständigkeit*
  - Asking for assistance and for confirmation of approach  
*Um Hilfestellung bitten und sich die Herangehensweise bestätigen lassen*

Lock schlußfolgert, daß die Interpretations- und Planungsfähigkeiten stark miteinander gekoppelt sind. Demzufolge kann aus Lock's Bewertungsmaßstab ein weiteres Paradigma für die Klassifizierung praktischer Tests entwickelt werden. Diese Elemente werden mit *Lobs*, *Lman*, *Lint*, *Lplan*, *Lreport* und *Lself* bezeichnet.

## OBE

Ergebnisorientierte Ausbildung (OBE) in Südafrika: Die sieben spezifischen Ergebnisse im Ausbildungsbereich Technik [6].

In Südafrika wird OBE gegenwärtig an den Schulen, Universitäten und Techniken implementiert. Die sieben spezifischen Ergebnisse im Bereich Technologie werden wie folgend beschrieben:

- Verstehe den technologischen Prozeß und wende ihn bei der Problemlösung und zur Befriedigung von Bedürfnissen an (SO1).

- Verwende vielfältiges technologisches Wissen und Fertigkeiten ethisch und verantwortlich (SO2).
- Dringe in den Prozeß ein und nutze die Daten für technologische Zwecke (SO3).
- Wähle Produkte und Systeme aus und bewerte sie (SO4).
- Zeige Verständnis dafür, wie verschiedene Gesellschaften technologische Lösungen für spezielle Probleme finden und anwenden (SO5).
- Zeige Verständnis für die Bedeutung der Technologie (SO6).
- Zeige Dein Verständnis dafür, wie Technologie unterschiedliche gesellschaftliche Strömungen widerspiegeln könnte und entwerfe verantwortungsbewußte und ethische Strategien um diesen entgegenzukommen (SO7).

## Franus

Franus führt eine vergleichende Analyse zwischen 5 Subsystemen des Denkens durch: kognitiv, technisch, künstlerisch, musisch und literarisch. Er verwendet 10 Kriterien um diese 5 Subsysteme zu vergleichen [7]. Die Subsysteme des Denkens bilden die Kategorien *Fcog*, *Ftech*, *Fart*, *Fmus* und *Flit*, wobei *F* den Bezug zu Franus herstellt.

## METHODIK

Okebukola und Ogunniyi empfehlen vier Herangehensweisen für die Laborarbeit. Diese sind:

1. Um den Wissensstand der Studenten in den Naturwissenschaften zu erhöhen sollten sie von den Ausbildern zur Zusammenarbeit im Labor angehalten werden.
2. Zur Verbesserung des Leistungsniveaus ist es von Vorteil, wenn besonders begabte Studenten in Gruppen zusammenarbeiten.
3. Die Leistungsfähigkeit schwächerer Studenten kann eher verbessert werden, wenn sie in Gruppen mit begabten und eher durchschnittlichen Studenten zusammenarbeiten.
4. Bezüglich ihrer Fähigkeiten gemischte oder heterogene Gruppen bei der Laborarbeit wirken sich effektiver auf die Steigerung der Leistung der schwächeren Studenten aus, als eher auf Wettkampf ausgerichtete Gruppenstrukturen [12]. Daher wurde diese spezielle Form der Gruppenarbeit während der verschiedenen Entwicklungsstadien dieser Studie angewendet, d.h. die Diskussion zwischen den Studenten der Arbeitsgruppen wurden gefördert.



## VORAUSGEHENDE UNTERSUCHUNGEN (FEBRUAR – DEZEMBER 1999)

Die Tests in diesem Programm wurden entsprechend der Frage ausgewählt, inwieweit sie für das Wissen auf dem Gebiet der Naturwissenschaften und Technik von Bedeutung sind. Diese Herangehensweise wurde von erfahrenen Lehrern (Physik), z.B. Ogunniyi bestätigt [13].

Die Pilotversuche wurden mit mehreren Gruppen durchgeführt, deren Mitglieder die jeweiligen Antworten miteinander diskutieren konnten. Danach schrieb jeder Student seine Antwort für sich nieder. Auf dem Antwortbogen (Testauswertebogen) stand zusätzlich Platz zur Verfügung auf dem die Betreuer ihre Beurteilung zu jedem einzelnen Test eintragen konnten.

Die Langzeituntersuchung umfaßt 34 Basistests für Physik und Technologie. Jeder Test enthält eine kurze Einführung und elementare Beschreibung der verwendeten Geräte und wurde auf schwarzem Hintergrund auf Schautafeln dargestellt. Tabelle 1

beschreibt einige dieser Tests. Während der Tests wurden die Studenten von Wissenschaftlern beobachtet und ihre Dialoge aufgezeichnet.

Die Tests wurden von unterschiedlichen Gruppen, bestehend aus Studenten und Lehrern 1999 ergänzt und verfeinert.

## ERGEBNISSE

- Die Entwicklung, Verbesserung, Beurteilung und Klassifizierung der 34 Testversuche wurde aufgezeichnet und zusammengefaßt. Durch die Einbeziehung von 11 verschiedenen Versuchsgruppen über einen Zeitraum von 10 Monaten wurde die Effektivität dieser Test erhöht.
- Tabelle 2 zeigt die Klassifikation einiger der 34 Testversuche, welche die Gruppen 3, 6 und 9 entsprechend den Kategorien von Gardner, White, Solomon, Lock, OBE und Franus eingeteilt haben.
- Während und nach den 11 Durchgängen wurden viele der praktischen Testumgeschriebe und die

Tabelle 1: Ausgewählte Tests des Programms.

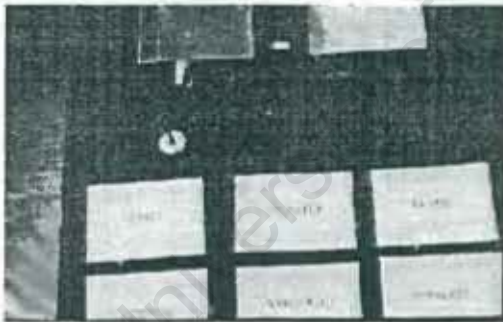

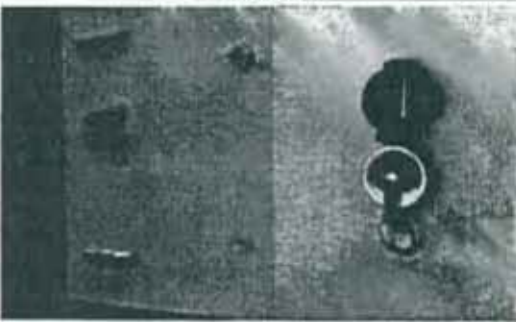
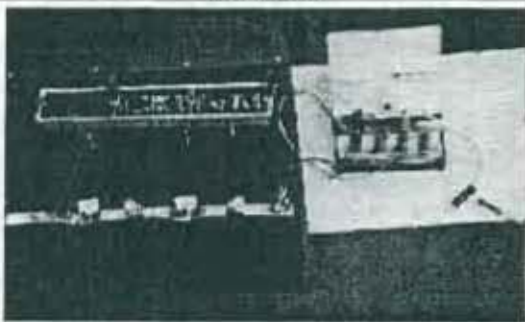
Schritt Figur	Schritt 1	Schritt 6
		
Bemerkung	Wähle das/die Merkmale aus, die durch die Benutzung dieses speziellen Gerätes gemessen oder bestimmt werden können.	Sie Dir diese 3 Schuhe genau an und finde denjenigen heraus, der den höchsten Druck erzeugt, wenn ihn die gleiche Person trägt.
Schritt Figur	Schritt 8	Schritt 20
		
Bemerkung	Sie Dir die Magneten und den Kompass an und finde den Nordpol für jeden Magneten.	Sieh Dir den Schaltkreis an: <ul style="list-style-type: none"> <li>• Messe den Spannungsabfall zwischen den Punkten A und B.</li> <li>• Schätze den Spannungsabfall zwischen Punkt B und C ab.</li> </ul>

Tabelle 2: Klassifikation von 6 Testversuchen entsprechend den Kategorien von Gardner, White, Solomon, Lock, Franus und OBE.

Schritt	Klassifikation
Schritt 1	W int, W prop, W cog, S P, S I L int, L rep, L self, L plan SO1, SO2, SO3,
Schritt 6	W string, W prop, G intra S H, S R L int, L rep, L plan SO1, SO2, SO3, SO4, SO5, SO6,
Schritt 8	W string, W mot G lm, G bk S P, S R L obs, L int, L rep, L plan, L man SO1, SO2, SO3, SO4, SO5, SO6
Schritt 17	W string, W epi G lm, G ling, G inter S H, S V, L obs, L int, L rep, L man, L plan SO1, SO2, SO3, SO4
Schritt 20	W int, W string, W cog, W mot G lm, G bk, G spat, G inter, G intra S P, S I, S R L obs, L man, L int, L plan, L rep, L self SO1, SO2, SO3, SO4, SO5
Schritt 22	W int, W string, W prop, W cog, W mot G lm, G bk, G intra S I L obs, L man, L int, L plan, L rep SO1, SO2, SO3, SO4

verwendeten Geräte auf ihre Genauigkeit und Zuverlässigkeit bei wiederholtem Gebrauch hin untersucht.

- Als ein Ergebnis der 11 Vorversuche die dazu herangezogen wurden das theoretische und praktische Verständnis in der Wissenschaft zu beurteilen, wurde ihre Anzahl auf 10 in der nächsten Stufe reduziert. Dadurch soll eine größere Anzahl von unterschiedlichen Testgruppen erreicht werden.

## DISKUSSION

Entsprechen den in Tabelle 2 angegebenen Ergebnissen für verschiedene Test läßt sich schlußfolgern, daß White's Kategorien für das Gedächtnis in der Theorie des Lernen besonders relevant sind. Lock's System für die praktische Arbeit kann ebenfalls eine hohe Bedeutung zugemessen werden. Im Gegensatz dazu werden die Kategorien nach Solomon, obgleich sehr umfassend werden sie im gegenwärtigen Programm nicht als besonders relevant eingestuft.

## SCHLUSSFOLGERUNGEN, ANREGUNGEN UND EMPFEHLUNGEN

Seit die Menschen damit begonnen haben Wissenschaft und Technologie zu lehren wird versucht, die akademische Wissenschaft und Technologie mit der realen Welt zu verbinden. Demzufolge ist auch in Südafrika ein großer Bedarf nach Programmen entstanden, um das praktische wissenschaftliche und technische Verständnis von Schülern und Lehrern in weiten Bereichen von Wissenschaft und Technologie zu untersuchen und zu bewerten. Speziell sei hier der Bereich Physik für junge Ingenieure erwähnt.

Der Mangel an praktischer Arbeit im Bereich Wissenschaft und Technik an den Schulen kann als einer der Gründe betrachtet werden, weshalb auch in Entwicklungsländern Wissenschaft und Technik als zu abstrakt und mit wenig Bezug zum realen Leben angesehen werden.

Daraus wird geschlossen, daß die Entwicklung und Anfertigung nützlicher, umfassender, aufregender, klarer und interessanter Tests für das praktische Verständnis in Wissenschaft und Technik eine zeitgemäße Erscheinung ist, die unter Umständen mehrere Testreihen und Modifikationen erfordern kann. Diese Tests müssen nicht nur theoretisch gut durchdacht und kohärent sein, sondern auch nützlich und von Studenten mit unterschiedlichen schulischem Hintergrund anwendbar. Dies gilt insbesondere in Südafrika mit einem sich schnell verändernden Entwicklungsstand.

## DANKSAGUNG

Der Autor möchte sich hiermit für die großzügige finanzielle Unterstützung durch den Forschungsausschuß der Universität Cape Town während der ersten Phase des Projektes (1999) bedanken. Mein Dank gilt außerdem den Lehrern und Studenten, die sich für die ersten 8 Testversuche zur Verfügung gestellt haben. Für ihre ständige Ermunterung, die kritische Durchsicht des Manuskripts und hilfreiche Hinweise sei den Prof. M. Ogunniyi, Prof. C. Lindner, Prof. M. Kahn, Prof. K. Rochford, Prof. S. Allie, Dr A. Buffler, Dr L. Kaunda und Dr A. Eryilmaz recht herzlich gedankt.

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## BIOGRAPHIE



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Er legte Artikel und Tagungsbeiträge zu praktischen Fragen der Physikausbildung auf verschiedenen Seminaren und nationalen Konferenzen vor.



# NASIONALE VAKDIDAKTIEK/ LEERAREA-SIMPOSIUM

## NATIONAL SUBJECT DIDACTICS/ LEARNING AREA SYMPOSIUM



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UNIVERSITEIT VAN STELLENBOSCH  
UNIVERSITY OF STELLENBOSCH

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### *KURRIKULUM 2005: RETORIEK EN REALITEIT* *CURRICULUM 2005: RHETORIC AND REALITY*

14 – 17 SEPTEMBER 1999

REFERAATOPSOMMINGS, WERKSEMINARE EN PLAKKATE  
ABSTRACTS, WORKSHOPS AND POSTERS

MJ SMIT & AS JORDAAN

30.	OMGEWINGSOPVOEDING AS OPVOEDINGSVERRYKING: ENKELE REFLEKSIES OP DIE ONTWIKKELING VAN OMGEWINGSOPVOEDING IN DIE FAKULTEIT OPVOEDKUNDE, UNIVERSITEIT VAN STELLENBOSCH Prof Danie Schreuder	38
31.	DISTINGUISHING BETWEEN THE RHETORIC AND THE REALITY: THE CASE OF HISTORY IN CURRICULUM 2005 Rob Siebörger	39
32.	CURRICULUM REFORM AND TEACHING IN SOUTH AFRICA: MAKING A 'PARADIGM SHIFT' Rob Siebörger & Goretli Nakabugo	40
33.	CHANGING FROM TEACHER-CENTRED, CONTENT-BASED TO STUDENT-CENTRED, OUTCOMES-BASED LEARNING AT COLLEGES OF EDUCATION Colleen Smith, Cliff Malcolm & Jill Owens	41
34.	CURRICULUM 2005: HITHERTO MJ Thamane & LT Mabasa	42
35.	DIE ONTWIKKELING VAN LEERPROGRAMME VIR DIE LEERAREA MENSLEKE EN SOSIALE WETENSKAPPE Prof R van der Merwe	43
36.	DECONSTRUCTING THE OBE MASKS OF LEARNING Yusef Waghid	45

### WERKSWINKELS/WORKSHOPS

1.	EMPOWERING EDUCATORS TOWARDS THE EFFECTIVE IMPLEMENTATION OF OBE: A RESEARCH-BASED PROGRAM A Carl, C Roux, MJ Smit, B Rhodes, L Rogers, E Ungerer, R Ferguson & M Ferreira	46
2.	THE DEVELOPMENT OF PERFORMANCE TASKS FOR LEARNING Robert Gerber & Elsa Lombard	47
3.	THE DEVELOPMENT OF GRIDS AND RUBRICS AS ASSESSMENT TOOLS Robert Gerber & Elsa Lombard	48
4.	"WORKING TOWARDS A MORE RELEVANT SCIENCE CURRICULUM: IDEAS FROM THE SCIENCE THROUGH APPLICATION PROJECT" (STAP) Brian Gray & Sam Noemdoe	49
5.	"INNOVATIVE IDEAS FOR THE TEACHING OF SCIENCE AND IMPLICATIONS FOR TEACHER EDUCATION PROGRAMMES" Brian Gray & Sam Noemdoe	50

6.	PRACTICAL SCIENTIFIC LITERACY – THE DEVELOPMENT, VALIDATION AND CLASSIFICATION OF PRACTICAL TEST ITEMS IN PHYSICS AND BIOLOGY A Inal, K Rochford & E Abrahams	51
7.	DIE TOEPASSING VAN DIE SEWE SPESIFIEKE UITKOMSTE VIR DIE LEERAREA TAAL, GELETTERDHEID EN KOMMUNIKASIE (TGK) Mari Latti & Sonia Gouws	53
8.	CURRICULUM 2005's OBE AND ME: THE WORKSHOP Al Lindstrom	55
9.	WRITING CURRICULUM AS STORY Cliff Malcolm	57

### PLAKKAAT/POSTER

1.	"THE SCIENCE THROUGH APPLICATIONS PROJECT" (STAP) B Gray & S Noemdoe	
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## **PRACTICAL SCIENTIFIC LITERACY – THE DEVELOPMENT, VALIDATION AND CLASSIFICATION OF PRACTICAL TEST ITEMS IN PHYSICS AND BIOLOGY**

**A INAL, K ROCHFORD & E ABRAHAMS  
SCHOOL OF EDUCATION  
UNIVERSITY OF CAPE TOWN**

The aim of this workshop is to enable participants – who will be science and/or biology teachers – to develop, validate, handle and classify approximately 40 basic practical/manipulative test items drawn from the disciplines of school biology and physical science. The ultimate goal is to reach a possible group consensus on what it means for a person to be identified as "practically skilled" in the area of science and technological literacy.

The "Preamble" to the Department of Education's Policy Document of October 1997: Natural Sciences: Senior Phase states on page NS-4:

Experimental work is a defining characteristic of science and should feature prominently in science Learning Programmes. Wherever possible, practical work should involve active learner participation.

The tasks presented in the workshop will be selected to illustrate assessment criteria and range statements which explain the attainment of the Specific Objectives SO1 "Use process skills...", and SO2: "Demonstrate an understanding of concepts and principles..." in the Natural Sciences.

The Rationale for the Learning Area "The Natural Sciences" states:

The development of appropriate skills, knowledge and attitudes and an understanding of the principles and processes of the Natural Sciences enable learners to make sense of their natural world...and...contribute to the creation and shaping of work opportunities.

The programme of practical test items has been developed in harmony with this rationale.

Each of the approximately 40 illustrative items of practical/manipulative literacy is individually mounted and labelled, and the wording of the instructions for the items has been revised and developed in earlier trials and pilot studies in a wide variety of contexts and schools. The working items include examples from the topic areas of electricity, optics, magnetism, mechanics, animal life, human physiology, etc. The classification theories of several leading science education theorists have been used to seek coherence amongst the items selected for the practical test programme.

The workshop is planned for both novice and experienced classroom science/biology teachers who are favourably disposed towards regular in-depth sessions of assigned practical work in schools. Lecturers in science teacher education are also welcome to participate and to offer their insights into the manipulative processes being assessed.

First National Conference for Teachers

**SCIENCE & TECHNOLOGY  
EDUCATION CONFERENCE**

***Proceedings***  
**STEC 2000**



**22 - 24 September 2000**  
Cape Town College of Education  
Cape Town, South Africa

# Proceedings of the Science and Technology Education Conference 2000

22-24 September 2000, Cape Town

## Contents

Background to STEC 2000 .....	v
<b>PART 1: OPENING ADDRESS .....</b>	<b>1-3</b>
Address by the Chief Director of the Department of Arts, Culture, Science and Technology .....	1
<b>PART 2: PAPERS AND SELECTED WORKSHOP PRESENTATIONS<sup>1</sup> .....</b>	<b>4-187</b>
<b>Abrahams, E., Rochford, K. &amp; Inal, A.</b> – The development, evaluation and implementation of practical assessment items in physics and biology for Curriculum 2005 .....	4
<b>Abratt, V., Miller, C., Suir, V., Collett, H. &amp; Scholtz, Z.</b> – Practical biology: Teaching principles and developing skills .....	8
<b>Chetty, S.</b> – Problem solving in biology - A workshop .....	12
<b>Davidowitz, B. &amp; Rollnick, M.</b> – "I thought it was brilliant" - Flow diagrams as a learning tool .....	16
<b>Davies, N.</b> – Can matric results in physical science at low-performance schools be sharply improved? - Directions in the work of the Secondary Schools Partnership Project .....	21
<b>Dyasi, R.E. &amp; Dyasi, H.M.</b> – Changing perspective and practice in science teaching: Science teacher educators' work .....	25
<b>George, H. &amp; van Schoor, E.</b> – The Centre of Science and Technology: An alternative approach to science and mathematics teaching in the township context .....	33
<b>Govender, N.</b> – A phenomenographic study of physics students' experiences of sign conventions in mechanics .....	36
<b>Hartley, M.S.</b> – Using student perception to improve the learning environment of a Grade 8 science class: A case study .....	41
<b>Jacobs, K.</b> – Evaluation of the drawings in a new South African textbook for natural science and technology by high school learners and their teachers: A progress study .....	44
<b>Khoali, T., Rollnick, M. &amp; Bapoo, A.</b> – What laboratory experience do matriculation students have? .....	48
<b>Le Roux, E.</b> – The Internet and technology - A workshop .....	52
<b>Malcolm, C.</b> – Choosing the content of science .....	56
<b>Malcolm, C., Keane, M. &amp; Zwane, K.</b> – Working together, scientifically .....	63
<b>Mitchley, A.</b> – What is technology education? .....	69
<b>Mogashoa, R.</b> – Is the South African science and technology system satisfactorily diversified to ensure an optimisation of participation and maximisation of quality outputs and outcomes? .....	76
<b>Mphahlele, M.</b> – Towards a single science and technology educators' association: Reflections, challenges and future directions .....	82
<b>Mphahlele, M. &amp; Sokopo, Z.</b> – Factors impacting on district performance in mathematics and science .....	86
<b>Mumba, F., White, M. &amp; Rollnick, M.</b> – What abilities and knowledge do first-year chemistry lecturers and high school physical science teachers perceive as important for incoming students at the University of the Witwatersrand? .....	92
<b>Naidoo, P.</b> – Learning from botany text: A cognitive processing approach .....	96
<b>Naidoo, P.D.</b> – "Multicultural science for all" - A reality .....	105
<b>Naidoo, S.</b> – Assessing teaching and learning of concepts in biology through performance in the General Science Olympiad .....	111
<b>Ogunniyi, M.B.</b> – Pupils' ideas and perceptions about science and technology .....	117
<b>Pillay, T.</b> – Structured teaching packages: A solution to inadequately resourced schools in rural KwaZulu-Natal .....	122
<b>Puhl, C.A.</b> – Teaching the language of science – A workshop .....	126
<b>Rasekoala, E.</b> – The African Renaissance in science & technology education: Quo vadis? .....	130
<b>Rhodes, S. &amp; Abel, L.</b> – Mediation of attitudes, skills and values in science .....	137

<sup>1</sup> Certain workshop presenters have written papers that augment the workshops they gave at STEC 2000. These papers provide some of the insights needed for a deeper understanding of the particular workshop topics. The papers are not merely summaries of procedures followed in each workshop. We therefore considered that these "workshop papers" would be useful additions to the proceedings and have included them with the papers presented during the conference.

# The development, evaluation and implementation of practical assessment items in physics and biology for Curriculum 2005

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The aim of this paper, accompanied with a workshop, is to enable the participants - who will be science and/or biology teachers - to implement, validate, handle and classify approximately ten basic practical/manipulative assessment items drawn from the disciplines of school biology and physical science. The ultimate goal is to reach a possible group consensus on what it means for a person to be identified as "practically skilled" in the area of science and biological literacy.

The "preamble" to the Department of Education Policy Document of October 1997: Natural Sciences: Senior Phase states on page NS-4: "Experimental work is a defining characteristic of science and should feature prominently in science Learning Programmes. Where possible, practical work should involve active learner participation." The urgent need for the provision of practical science facilities, and other resources, especially in rural areas, on a need-to-have, able-to-use basis, linked with in-service education, is acknowledged. The rationale for the Learning Area "The Natural Sciences" states:

"The development of appropriate skills, knowledge and attitudes and an understanding of the principles and processes of the Natural Sciences enable learners to make sense of their natural world... and... contribute to the creation and shaping of work opportunities."

In the long term, the whole study will investigate sample performance skills or levels of practical scientific and biological literacy of senior high school physical science and biology learners in a wide variety of geographical and cultural contexts.

## Introduction

The first purpose of this conference presentation is to enable the participants - who will be science and/or biology teachers - to develop, evaluate, classify and implement basic practical assessment items drawn from the disciplines of school biology and physical science. The ultimate goal is to reach a consensus on what it means for a person to be identified as "practically skilled" in selected areas of science and biological literacy.

Secondly, a future extended study aims to investigate whether there will be a significant difference between culturally diverse samples of high school biology students on longer tests comprising ten practical items measuring identification and performance skills, and content achievement.

## Theoretical framework

In physical science the classification of the assessment items according to different theories and outcomes of learning science and assessment frameworks in science will be explored and corroborated or modified for a South African context. The theories of White (1988), Gardner (1983) and Franus (1992), outcomes advocated by Solomon (1996) and outcomes-based education (1997), Lock and Davies (1987) and assessment frameworks of Lock (1986) and Assessment Performance Units will be used to classify the items. In biology, we are also going to investigate the significance of religious traditions, cultural perception and classification with reference to various aspects of living and dead animals. Theories of social aversion and social and cultural acceptance, as described by Jegede (1991) and Bagozzi (1978) will be used to assist with the interpretation of the data.

## Background to the investigation, and its importance

To investigate the scientific literacy levels and the conceptual difficulties of science learners and teachers, many investigations have been conducted during the last few decades, e.g. Galili and Bar (1992), Twigger *et al.*, Gilbert, Watts and Osborne (1982), Zhaoyao (1993), Laugksch and Spargo (1996), Palmer (1997), Trumper (1996). However, in most of these studies, the questions used were paper-and-pencil type tests.

For the term 'scientific literacy' there are a number of different assumptions, interpretations, conceptions and perspectives of what the term means, what introducing the concept could achieve, and how it is constituted (Laugksch, 1999). Laugksch categorised the interest groups involved in scientific literacy into four parties. These are 1) the science education community, 2) social scientists and public opinion researchers concerned with science and technology issues, 3) sociologists of science and science educators employing a sociological approach to scientific literacy and 4) formal and non-formal science education communities, and those involved in general science communication.

From the beginning of modern science in the 1600s there has been an interest and effort to close the gap between academic science and the life world of the learner. Today this deficiency has become an international challenge for every nation because of the rapid change in the practice of science, revolutionary changes in societies and the emergence of the information age (Hurd 1998). Hurd listed 25 attributes of a scientifically literate person. Three of them are as follows:

- To use science knowledge where appropriate in making life and social decisions, forming judgements, resolving problems and taking action.



- To recognise gaps, risks, limits and probabilities in making decisions involving some knowledge of science or technology.
- To recognise the everyday reality of ways in which science and technology serve human adaptive capacities, and enrich one's capital.

In a study which focused on context-dependency of pupil practical skills and the construct validity of practical skills, Lock (1990) compared pupil performance on a range of practical tasks with external examination grades awarded in biology and chemistry. He observed that observation and reporting skills appeared to be context-dependent whereas performance on the interpretation and self-reliance skills were generalisable. He also concluded that practical work should be given a prominent and discrete place in the assessment of science subjects.

Thus has arisen the need for a complementary programme to be developed to establish and investigate the practical scientific literacy of the learners and teachers, across a wide range of topics in science.

In 1996, Laugksch and Spargo developed a paper-and-pencil type test containing 472 true-false items, based on the literacy goals of the American Association for the Advancement of Science, with the intention that it be used as measures of scientific literacy. However, these items were not culturally diverse, nor were they essentially practical in nature.

Hands-on experience is integral to familiarising learners with difficult scientific concepts, as many learners find it difficult to visualise concepts without at least a practical demonstration. Hudson (1990:39) argued the value of practical work in science education and stated that all we could say is that some teachers are able to use practical work successfully with some children, and achieve some of their goals.

Hudson (1998) stated that there are many newcomers to the profession who are unsure about how best to design and implement hands-on work in school science. He suggested that practical work be reconceptualised in three associated purposes:

- 1 to help students learn science - acquire and develop conceptual and theoretical knowledge;
- 2 to help students learn about science - develop an understanding of the nature of the methods of science and an awareness of the complex interactions among science, technology, society and environment; and
- 3 to enable students to do science - to engage in and develop expertise in scientific enquiry and problem-solving.

He concluded that practical work could be a very powerful tool in developing students' conceptions and procedural understanding. It also assists in the development of the students' personal expertise.

While extensive research has been conducted into children's conceptions (e.g. Pfundt & Duit, 1994; Fensham, White & Gunstone, 1994) and children's views of science (e.g. Ogunniyi, 1998), the framework has been essentially science (subject) centred. It takes as given that "science" should be taught, with "science" defined by the knowledge and skills of the research scientist. Researchers such as Jegede (1995) have gone beyond children's conceptions

and classroom methods to explore African children's worldviews, how those worldviews facilitate science learning, and how science education might be adapted to contribute to students' development within their own worldviews (Malcom, Smith & Ovens, 1999).

As a result of the lack of practical work, many learners have perceived school science as abstract and having no relation with practical life, and they do not want to do science at higher levels (Abrahams & Rochford, 2000).

## Methodology

In the present study, two assessment programmes are being developed to assess levels of practical scientific literacy levels in selected areas of physics and biology in the South African context, specifically in the Western Cape.

In biology, instead of using the conventional paper-and-pen test questions, the assessment items utilise real organs of mammals. Their structures are flagged but not identified, and they are accompanied by sketches containing helpfully labelled structures. These supplementary materials help to assess the learners' skills of identification and recognition of detail in the reality of complex anatomical structures. In addition, data will be gathered by students to comment on their social/religious/cultural acceptance of working practically with fresh animal organs in the context of their ethical background and religious principles.

The items in physical science were selected on the basis of their being fundamental to knowledge of practical science and technology as agreed by a panel of experienced physics teachers, e.g. Ogunniyi (1999). The pilot trials were conducted in groups of participants in which members of the groups were free to discuss their responses with each other. Then each respondent wrote down his/her own responses individually. On the response sheets (item evaluation sheets) a space was supplied for the attendants to write their assessment and evaluation of each item.

Thirty-four basic practical physics and technology items have been developed. Each item contains a simple instruction with some elementary apparatus presented on mounted display boards with a black paper background. While participants are tested by the items, they are observed by the researcher, and their dialogues with each other were recorded by an audio recorder.

In the future study, ten of these 34 items will be used for qualitative and quantitative evaluation of the attendants.

The materials were trialled in depth, in sessions lasting one-and-a-half to two hours, amended and refined using 11 conveniently available and diverse samples of physical science and technology students/teachers/lecturers.

## Preliminary findings

- 1 Through the development, refinement, trialling and classification period of the 34 physics items, effectiveness of the items improved through increasing validation with 11 diverse classes of participants.
- 2 According to the responses for the rated classifications of physics items, White's categories of the memory appeared to be the most relevant theory of learning -

those of White, Gardner and Franus - for specific items. Lock's assessment framework for practical work in science was identified as being highly relevant to the current programme. Although Solomon's categories of outcomes seemed to be very comprehensive, it was not rated to be highly relevant to the current programme.

- 3 Many of the practical items were reworded during and following the 11 trials, and the components of apparatus of some items were checked for technical accuracy and reliability of functioning under repetitive use.
- 4 As a final outcome of the 11 preliminary studies, the number of items to be used to measure selected aspects of the practical scientific and practical literacy of the learners was reduced to ten during the next phase of the study. To reach more diverse groups of participants, with typically only 45-minute periods available for lectures or lessons, the study focuses on using only ten of the most important items in comparative studies between samples of participating learners.
- 5 The responses obtained from the participants in these pilot trials revealed that the learners found the following topics difficult:
  - Force and motion
  - Forces acting on an object.
  - The concept of work.
  - How to connect particular items of measurement apparatus in a circuit.
  - Distinguishing between concave and convex surfaces.
  - Characteristics of different types of images formed by different lenses and mirrors such as real, virtual, inverted etc.
- 6 In the pilot trial held at Lanner House in Worcester, to evaluate the practical scientific literacy of learners, the learners enjoyed touching, identifying and labeling the various mammalian organs on display. Many of the learners were not familiar with the organs in their raw (uncooked) state. Many of the learners were able to identify and pin the correct label to the parts of the organs by referring to labeled diagrams. The learners worked in groups because the labeling process was slow. It was decided to change the method of evaluation of mastery of the practical skill technique
- 7 A further pilot trial was held at the University of Stellenbosch in the form of a workshop. Participants ranged from tertiary students to lecturers. Participants mentioned that they found it interesting to work with actual mammalian organs. They liked the idea of the of the statements which needed to be investigated practically and then ticked to indicate whether they agreed, disagreed or were not sure of their answer. They felt that this type of practical work could be useful and stimulating in a classroom situation. The responses were much easier to evaluate than in the first pilot trial. The data collected could be analysed with greater ease and accuracy.

## Discussion

As long as human beings have been trying to teach science and technology there has been an attempt to relate academic science and technology with the real world. Therefore, a special need has arisen in South Africa

for a new complementary programme to be developed to investigate and gauge the practical scientific and technological literacy of learners and teachers, across a wide range of topics in science and technology, with special reference to physics for aspirant young engineers. In developing countries, a lack of practical work in school science and technology could have been the reason for students perceiving science as abstract and not always related to practical life.

## Conclusion

It is concluded that the formulation, design and production of useful, comprehensible, credible, exciting, clear and interesting sets of diagnostic materials for assessing students' selected levels of practical scientific and technological literacy is a modern process which may involve more than a dozen successive trials and modifications. Not only must they be theoretically sound and coherent, but also items must be useful to, and acceptable by, a wide range of students in a very diverse set of teaching conditions in the new and developing South Africa.

As a general conclusion of the above-quoted researches and the preliminary results of the current study it can be concluded that practical work in science, technology and biology education holds a special importance and there is a lack of understanding of practical components of science and technology. Therefore we need to consider our school science and biology curricula in terms of quality practical work. In this context the current study is an attempt to introduce a practical assessment programme as a part of practical work in science and technology education.

## Acknowledgements

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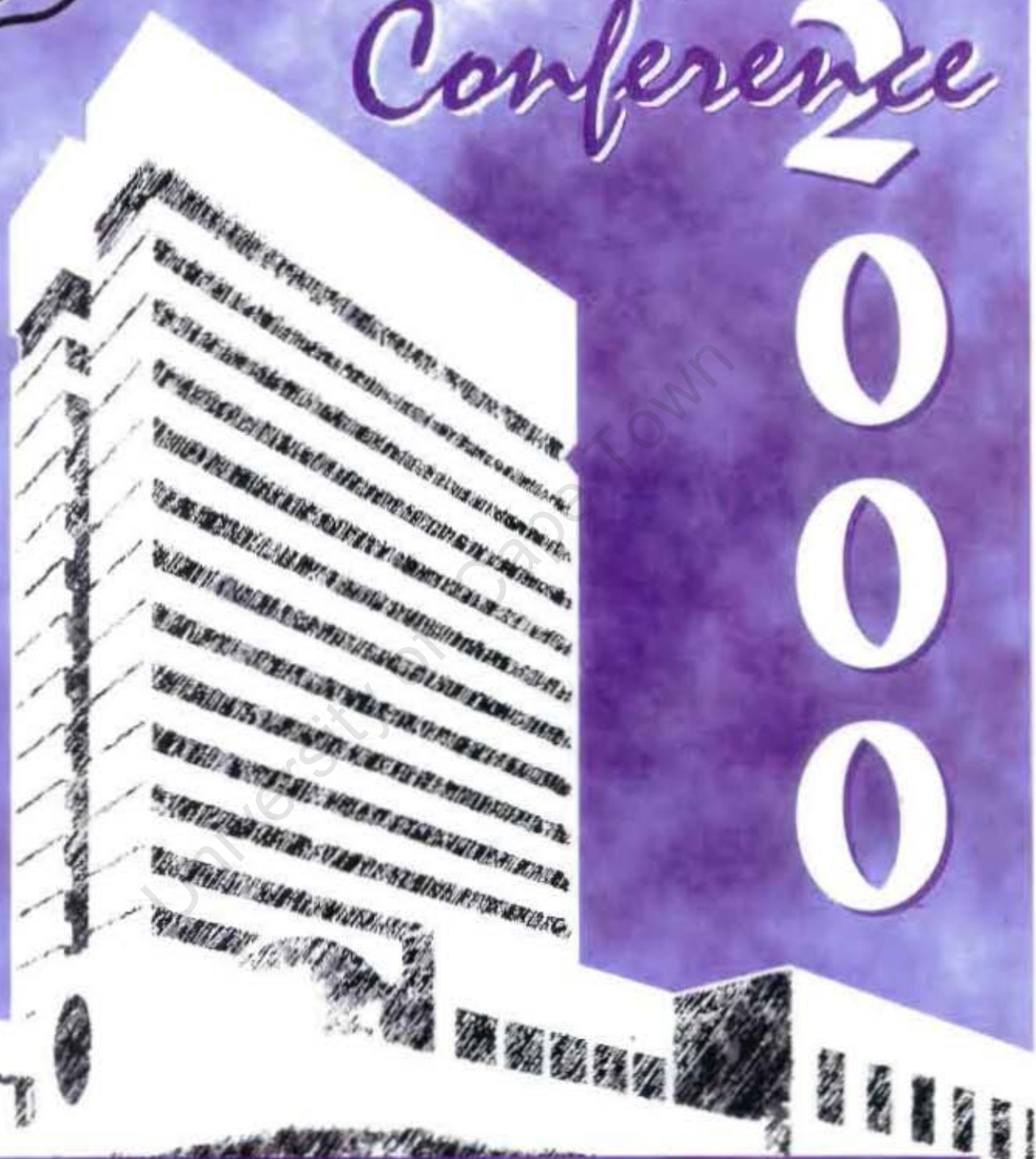




**Southern African Association for Research in  
Mathematics & Science Education**

# Conference

# 2000



**Proceedings of the  
8th Annual Conference of the Southern African Association for  
Research in Mathematics and Science Education (SAARMSE)**

**UNIVERSITY OF PORT ELIZABETH 19 - 22 JANUARY 2000**



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<b>Glover H. nad King Lonnie ( Department of Science, Maths and Technology Education, University of Port Elizabeth )</b>	
<b>An Analysis of the Algebraic Misconceptions held by a group of Eastern Cape Intermediate Phase teacher</b>	<b>152</b>
<b>Graven M( RADMASTE Centre, University of the Witwatersrand )</b>	
<b>What changes in Mathematics teacher identities are demanded by current curriculum change in South Africa ?</b>	<b>158</b>
<b>Hartley MS (University of Stellenboch )</b>	
<b>To assess the efficacy of an open day as a set Awareness Tool</b>	<b>162</b>
<b>Hobden P (CASME)</b>	
<b>That's a trick Question : Some Reasons why Students cannot solve the difficult Problems in Physical Science</b>	<b>168</b>
<b>Hobden S (Edgewood College of Education)</b>	
<b>Whatever are they thinking? A study of the personal beliefs of preservice teachers about teaching and learning Mathematics</b>	<b>175</b>
<b>Huddle PA (Department of Chemistry, University of the Witwatersrand)</b>	
<b>Active learning - A workshop of the mole concept. A report of research-in-Progress</b>	<b>181</b>
<b>Huddle PA (Department of Chemistry, University of Witwatersrand)</b>	
<b>Use of Poster Presentations to enhance Learning</b>	<b>186</b>
<b>Huillet D and Mutemba (Eduardo Mondlane University, Maputo , Mozambique)</b>	
<b>The Relation of Mozambican Secondary School Teachers to a Mathematical Concept : The case of limits of Functions</b>	<b>191</b>
<b>Hungwe G (Zimbabwe Open University)</b>	
<b>To what extent do Gender- Related attitudes Towards Mathematics differ at Primary and Secondary School level in Harare (Case Study )</b>	<b>197</b>
<b>Inal A and Rockford K (School of Education, University of Cape Town)</b>	
<b>The construction, Development and Classification of Test items in Practical Scientific Literacy in Physics and Biology</b>	<b>204</b>
<b>Itsley J and Webb P (Department of Science, Mathematics and Technology Education, University of Port Elizabeth) Alternative conceptions: The internal logic of teachers' understandings in science. See page x of contents.</b>	
<b>Kandemiri MBand Namasasu, O. (University of Zimbabwe)</b>	
<b>Awareness of Mukuvisi River Pollution among Primary School Children in Mbare : A Case Study</b>	<b>210</b>

## THE CONSTRUCTION, DEVELOPMENT AND CLASSIFICATION OF TEST ITEMS IN PRACTICAL SCIENTIFIC LITERACY IN PHYSICS AND BIOLOGY

Inal, A and Rochford, K (School of Education, University of Cape Town)

### Abstract

*This study describes the development, validation and classification of thirty-four practical items in basic physics literacy. Using these items, the levels of practical scientific literacy of high school physics students, tertiary level students and teachers are to be compared both qualitatively and quantitatively. A similar study is evolving using practical items in biology.*

*The classification of the specially designed items by experienced teachers and academics constitutes an original and crucial part of the whole study. The objective is to assess the consensus of a panel of experienced science education academics on the six-way classification of the 34 items, using the theories of Gardner (1983), White (1988), Solomon (1996), Lock (1989), Franus (1992) and Outcomes Based Education (1997) to try to match the theories with the actual apparatus and manipulating skills in the laboratory itself.*

### Purpose of the investigation

The first purpose of this study is to describe, illustrate and demonstrate the development and validation of diagnostic practical items of basics physics literacy. These are to be utilised, for testing a basic understanding of the elements of some topics in physics using actual apparatus, by designing the simple items in such a way that they are "user-friendly" to the general public, as well as to students. Items in basic practical biology literacy are also being trialled.

The whole long-term study aims to investigate and compare sample performance skills, or levels of practical scientific and technological literacy, of senior high school physical science students, tertiary level students and teachers. A parallel study is occurring in biology.

Secondly it aims to investigate in the future whether there will be a significant difference between the performance achievement of high school physical science students, tertiary level students and teachers on a longer test comprising thirty-four practical items.

As a third aim, the development of the multiple intelligence of respondents - specifically in the domain of practical scientific and technological manipulative literacy after White (1988), Gardner (1983), Solomon (1996), Lock (1989), Franus (1992) and Outcomes Based Education (1997) - will be explored and corroborated or modified for a South African context.

The first aim (described above) is the main focus of this report; together with the design of methods for obtaining agreement, by consensus, on the classification of the items according to the categories of Solomon, White, Gardner, Lock, Franus and OBE.

### Background to the investigation

For the term 'scientific literacy' there are a number of different assumptions, interpretations, conceptions and perspectives of what the term means, what introducing the concept could achieve, and how it is constituted (Laugksch, 1999). Laugksch categorised the interest group involved in scientific literacy into four parties. These are 1) the science education community,

2) social scientists and public opinion researchers concerned with science and technology issues, 3) sociologists of science and science educators employing a sociological approach to scientific literacy and 4) formal and non-formal science education community, and those involved in general science communication.

From the beginning of modern science in the 1600s there has been an interest and effort to close the gap between academic science and the lifeworld of the learner. Today this deficiency has become an international challenge for every nation because of the rapid change in the practice of science, revolutionary changes in societies and the emergence of information age (Hurd 1998). Hurd listed twenty five attributes of a scientifically literate person. Three of them are as follows:

- To use science knowledge where appropriate in making life and social decisions, forming judgements, resolving problems and taking action.
- To recognise gaps, risks, limits and probabilities in making decisions involving a knowledge of science or technology.
- To recognise the everyday reality of ways in which science and technology serve human adaptive capacities, and enrich one's capital.

Black, Solomon and Stuart (1986) investigated the awareness of dangers of electricity of 11-12 and 13-14 years old pupils, and they saw that 61% of the 11-12 and 35% of the 13-14 year old pupils could mention the dangers of electricity. Finally they concluded that the pupils create meaning for the scientific concepts through their personal daily lives.

In a study which focused on context-dependency of pupil practical skills and the construct validity of practical skills, Lock (1990) compared pupil performance on a range of practical tasks with external examination grades awarded in biology and chemistry. He observed that observation and reporting skills appeared to be context-dependent whereas performance on the interpretation and self-reliance skills were generalisable. He also concluded that practical work should be given a prominent and discrete place in the assessment of science subjects.

To investigate the scientific literacy levels and the conceptual difficulties of science learners and teachers, many investigations have been done during the last few decades, e.g. Galili and Bar (1992), Twigger et al, Gilbert, Watts and Osborne (1982), Zhaoyao (1993), Laugksch & Spargo (1996), Palmer (1997), Trumper (1996). However in most of these studies the questions used were paper and pencil type tests.

There has been a need for a complementary programme to be developed to investigate the practical scientific literacy of the learners and teachers, across a wide range of topics in science.

As a result of the lack of practical work, many learners have perceived school science as abstract and having no relation with practical life, and they do not want to do science at higher levels.

In the present study, a programme is being developed to assess the practical scientific literacy levels in selected areas of physics and biology in the South African context.

#### **Pilot studies from february to september 1999**

To develop and test the current programme seven pilot trials have been conducted so far. Four of the pilot trials were conducted with high school physical science students, one of them was conducted with physical and general science teachers-

in-training at the University of Cape Town, one was conducted with experienced science teachers and academicians at the University of the Western Cape, and one with primary teachers-in-training at the University of Stellenbosch.

The items in this programme were selected on the basis of their being fundamental to a knowledge of practical science and technology as agreed by a panel of experienced physics teachers, e.g. Ogunniyi (1999). The pilot trials were conducted using participants in which members of the groups were free to discuss their responses with each other. Then each respondent wrote down his/her own responses individually. On the response sheets (item evaluation sheets) a space was supplied for the attendants to write their professional assessment and evaluation of each item.

The whole long term study comprises 34 basic practical physics items and 20 practical biology items. Each item contains a simple instruction with some elementary apparatus presented on mounted display boards with a black paper background. Figures attached in Appendix 1 show photographs of the apparatus and the instructions of some of the items, as well as the trial classifications according to the categories of White, Gardner, Solomon, Lock, Franus and OBE, as agreed upon by a panel of experienced science educators. While the participants go through the items they are observed by the researcher, and their dialogues with each other are recorded by an audio recorder.

### **Trial Samples**

The materials have been trialled, amended and refined in 1999 using seven conveniently available samples of physical science students/teachers/lecturers:

Sample 1. Four general and physical science teachers-in-training at University of Cape Town.

Sample 2. Five grade eleven physical science students at St. George's Grammar High School.

Sample 3. Eight science teachers and academicians at University of the Western Cape.

Sample 4. Fourteen grade ten, eleven and twelve physical science students from a historically disadvantaged physical science class at Oscar Mpeta High School.

Sample 5. Sixteen grade five-seven science students at Lanner House Primary School, Worcester.

Sample 6. Twenty-four grade eight-eleven students, from different schools in Western Cape, attending the Science EXPO at the Education Building, UCT.

Sample 7. Six primary teachers-in-training at the University of Stellenbosch.

### **Respondents' evaluation of the programme as a whole**

Commenting on the physical science practical exercise as a whole, the eleven most constructive qualitative remarks recorded from participants during the three pilot trials were as follows:

1. The instructions must be as clear as possible and must not be misleading.
2. The apparatus must be appropriate and simple.
3. Only the necessary apparatus must be supplied without any missing item or detail.
4. The prior knowledge of the learners must be considered. The items must be at the levels of the learners' knowledge.
5. The learners must be observed very carefully during the administration of the programme. Everything they say and do must be recorded in order to perfect each item as a credible test of practical scientific literacy during the pilot trials.

6. Strange items that the students might have never come across must not be involved in the programme. (The items must be in the area of proximal development of the learners.)
7. The target group for the items must be stated clearly.
8. The response that is expected from the learner must be identified clearly before the administration of the programme.
9. The number of the students in one group must not be more than three, and every member of the group must be given the opportunity to handle the apparatus.
10. The space supplied for each item must be arranged so that the learners can carry out the demonstrations and experiments.
11. The theoretical knowledge which is necessary for each item must also be identified.

The most serious shortcomings of the programme in its initial phases were described by various participant as:

- Some of the instructions were ambiguous and misleading. (These were specified).
- Some items of apparatus were not clear. (These were specified).
- The answer sheet was incomplete and not prepared well.
- During the administration of the test, the number of learners in one group was too large.
- Some signs and symbols that the students did not know, were used.

Nevertheless, all lecturers, teachers, students and pupils who participated in the seven trials of the development of the materials described the exercise as "well worthwhile; to be encouraged enthusiastically; very effective learning", etc.

### Conclusion of the preliminary results

It is concluded that the formulation, design and production of useful, comprehensible, credible, clear and interesting diagnostic materials for assessing students' levels of practical scientific literacy is a process which may involve more than half a dozen successive trials and modifications. Not only must they be theoretically sound and coherent, but items must be useful to, and acceptable by, a wide range of students in a very diverse set of teaching conditions in the new and developing South Africa.

### Future Samples

The anticipated future samples are:

- N=40 physical science teachers/demonstrators/lecturers;
- N=40 physical science students (high school);
- N=40 physical science students (tertiary level), and so on;

### Acknowledgements

The generous financial assistance of the University Research Committee of the University of Cape Town to the published dissemination of the early phases of this research work in 1999 is hereby acknowledged with thanks. Thanks are also extended to all the helpful lecturers and teachers and students involved in the seven trial samples.

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INTEGRATING CONTENT  
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2 to 4 July 2001

## PROGRAMME AND ABSTRACTS



PENINSULA TECHNIKON

Bellville  
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## **LABELLING THE STRUCTURES OF ANATOMICAL SPECIMENS AND SIMPLE PHYSICAL SCIENCE APPARATUS AS A FORM OF LANGUAGE TEACHING: A REPORT ON A STUDY INVOLVING 560 HIGH SCHOOL BIOLOGY AND PHYSICS STUDENTS**

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### **Abstract**

The aim of this paper is to report on a study conducted at four schools in the Western Cape involving 618 high school biology and physical science students. In this study we focus on the successes and difficulties learners encounter with labelling instructions of practical assessment of science and teaching methods. Use of language in the science classroom will also be discussed.

This paper describes practices of labelling and forms of practical assessment in the classroom and analyses the value of selected practical items of basic scientific literacy - with special reference to four fresh mammalian organs in Biology and two practical assessment items in Physical Science. Focusing on instructional recognition and labelling we evaluate the responses of high school biology and science students to the identification of 20 anatomical structures in four organs and to lenses and mirrors. Our results are presented both qualitatively (using critical and categorical interpretive analysis of data) and quantitatively.

### **Introduction**

In the textbooks that employ an outcomes-based approach, the relevant topics are explained through various activities in which students need to acquire skills to use different apparatus, (e.g. Ayerst et al., 1999). Therefore, in an OBE approach, the learners are expected to be able to use, handle and make measurements with different items of simple apparatus and technology.

Guzzetti et al. (1997) studied the influence of text structures on conceptual change of physics students. One of their findings was that most frequently 55% of Physics students and 48% of Honours students reported that they learned concepts best from experiments, laboratories and hands-on activities. By contrast 37% of Physical World students stated that they learned best by studying their notes and repetition and memorizing.

The responses of students to an open-ended question on their opinions of the availability of specific items, and on the test as a whole, and on this type of labelling work will be examined, and conclusions will be made based on the attendants' ideas. It will be discussed whether the selected groups of respondents would prefer to have practical assessment in class or not.

### **Purpose of the study**

The aim of this paper is to discuss language and labelling issues in developing basic practical/manipulative assessment items drawn from the disciplines of school physical science and biology and also to report the preliminary result gathered from various groups of respondents. The data has been collected during 2000-2001 and involved 618 secondary and tertiary level students from different geographical and cultural areas where the respondents are speaking different home languages.

The practical items in physical science are examined according to different learning theories, assessment frameworks and learning outcomes in science. One of the theories of learning science is Gardner's theory of multiple intelligence where he identified various components of intelligences. Among these components are

linguistic intelligence and interpersonal intelligence that emphasizes the importance of communicating with other people effectively. However the classification of items deserves a separate discussion on its own and will not be discussed in this paper.

Lock identified six practical skills concerned in school science, one of them being to report the results of a practical investigation. Lock emphasized that it is important for a learner to use scientific language (written/verbal) accurately and effectively to report.

### **Importance of the problem**

Kahn (2000:19) stated that Science and Technology education plays a crucial role in the development of a country, and it can be considered as a measure of its development. Specially trained teachers with modern teaching methods must be injected into the schools to improve science and technology education.

The "preamble" to the Department of Education Policy Document of October 1997: Natural Sciences: Senior Phase states on page NS-4: "Experimental work is a defining characteristic of science and should feature prominently in science Learning Programmes. Where possible, practical work should involve active learner participation." The urgent need for the provision of practical science facilities, and other resources, especially in rural areas, on a need-to-have, able-to-use basis, linked with in-service education, is acknowledged.

The rationale for the learning Area "The Natural Sciences" states: "The development of appropriate skills, knowledge and attitudes and an understanding of the principles and processes of the Natural Sciences enable learners to make sense of their natural world... and... contribute to the creation and shaping of work opportunities" (page NS-5).

In South Africa, as in any modern democracy, we need a scientifically/technologically literate population. Democracy can take on real meaning only if a population exists which appreciates its demands. Industrial democracy cannot exist unless its citizens are competent participants in life, and understand well the processes at work in technical societies. The technologically literate person should also understand that citizens in democratic societies can have some say in which technologies are advanced and which are restrained. (Glover 1990:)

Race (1997:36) stated that some of the most important learning occurs in laboratory and associated work before and after the practical sessions. He emphasized the importance of assessing this learning and made ten suggestions regarding laboratory work. For example: Give clear guidance regarding the format of reports.

Solomon (1996) has described a comprehensive theory of the multiple contents of the public understanding of science and emphasized the importance of science for the personal development of the individual by enhancing his/her communication skills.

### **Merits and Limitations of labelling of anatomical structures**

The demerits of labelling anatomical specimens include the unavailability of fresh specimens, the lack of refrigerators or cold storage facilities, aversion to mammalian anatomical structures due to ethical reasons or personal principles. Labelling of anatomical structures could be categorised as practical work. The demerits of practical work include issues of time, parental expectations, public examinations, unavailability of required instructional material, unavailability of fresh anatomical structures, lack of clarity about curriculum reform, teachers' lack of skills and knowledge, and the initial mismatch between the teacher's "residual ideologies" and the principles underlying the curriculum innovation. Other obstacles relate to organisational arrangements such as role overload, rigid scheduling of times, reporting systems, and failure of administration to recognise and understand its role in change (Nolder, 1990; Newstead and Bennie, 1999).

Hands-on experience is integral to familiarising learners with difficult scientific concepts, as many learners find it difficult to visualise concepts without at least a practical demonstration. Hodson (1990:39) argued the value of practical work in science education and stated that all we could say is that some teachers are able to use practical work successfully with some children, and achieve some of their goals.

In the syllabus document of the Western Cape Education Department (1996) are the following policies:

#### *1- Physical science:*

1.1.2 To develop in learners the necessary skills, techniques and methods of science, such as handling of certain apparatus, the techniques of measuring and observation, information retrieval.

1.1.6 To introduce learners to the applications of science in everyday life and in industry.

1.3.3 The practical work forms an integral part of the syllabus and plays an important role in understanding scientific principles and phenomena. It must therefore be regarded as an essential aspect science teaching.

## *2- Biology:*

2.1. Learners should make their own observations of specimens and experiments.

2.2. Learners should learn how to handle and set up apparatus correctly.

2.3. Organisms should be observed in their natural environments.

2.4. Constant emphasis should be placed upon facts being understood, interpreted and applied rather than being merely memorised.

## *3- General Science*

2.2.3. To make learners aware of the role of science in everyday life and in the community.

2.3.1. Acquisition of a number of necessary basic skills and techniques.

2.3.2. The acquisition of standard experimental techniques which require more than one type of basic skill.

## **Attitudes and cultural issues**

According to Ogunniyi (1997), students' cultural beliefs are entrenched in their world views. Perusal through the literature indicates stark contrasts between the African mode of thought and that on which western science is based. One then wonders how African and other students of non-western decent, and who subscribe to traditional world-views, learn school science which is grounded in a western mode of thought (Mudaly, 1999:300).

The new political setting in South Africa has brought with it all the challenges of a multicultural classroom. Pupils of different cultural backgrounds now sit in the same science classrooms. Some pupils will find that their world views clash with that of current science. The science teacher can assist pupils to resolve the conflicts they face by applying culturally compatible instructional procedures or by identifying the contiguity between the two clashing world views. Otherwise, the pupil may suffer alienation or experience what has been termed "symbolic violence". Pupils who experience symbolic violence feel misplaced, hardly ask questions in class for fear of being ridiculed and fail to find reliable supportive cultural templates critical to their sense of identity (Ogunniyi, 1997:50).

## **Methodology**

In biology instead of using the conventional paper-and-pen test questions, the first battery of assessment items utilise and present actual fresh organs of mammals with their unidentified structures flagged, but displayed with accompanying sketches containing helpfully labelled structures as supplementary materials in order to assess their skills of identification and recognition of detail in the reality of complex anatomical structures. In addition, data will be gathered by students to comment on their social/ religious/ cultural acceptance of working practically with fresh animal organs in the context of their ethical background and religious principles. In biology a second battery of 27 paper-and-pencil test items physiology content was also used.

The physical science component of this particular study involves two items of practical items. In the first item the respondents were required to identify and label three types of mirrors namely concave, convex and plane mirrors. In the second item the students were asked to indicate which one of the two lenses (one double concave and a double convex lens) can form a real image of the window in their classroom. The much larger study, of which this paper is part, has investigated responses to ten items of apparatus.

Originally thirty-four items were developed and then for the final data collection, ten of these items were utilised.

In these two items the students were expected to be able to relate their theoretical knowledge that they usually learn in the classroom to the practical situation and to label and handle the real apparatus, not only to answer paper-and-pencil type of assessment.

### Samples

This study has been conducted in four high schools and involved 618 high school students and 30 student teachers at University of Cape Town. Twenty-four of the student teachers were primary school science students and nine of them were PGCE students who had a BSc degree.

The high school students that were involved in this study were from various geographical, cultural and linguistic groups in the Western Cape.

### Findings

**Table 1: Average scores of schools on the biology content questionnaire (out of 25) and on the practical biological labelling, out of 25.**

	School 1 (N=112)	School 2 (N=242)	School 3 (N=129)
Content questionnaire	13.59	16.31	10.55
Specimen labelling	20.98	18.00	16.16

Figure 1 and Table 1 clearly show that whereas the total sample of students obtained results of between 42% and 65% for the questionnaire (a paper-and-pencil test of knowledge of physiology content), they achieved between 64% and 84% for the labelling of the fresh organs. Although it is not always correct to compare the results of the two tasks due to their obvious difference in nature and purpose, it may give us an indication of the usefulness of labelling as a teaching method. The students that participated in the labelling exercise were convinced that what they have learnt during the practical will be remembered for a long time. Science and Biology teachers may want to take advantage of labelling as a method to improve the language skill of their students.

The qualitative findings were recorded by means of interviews. The questions asked by the first author (Abrahams) are given in italics, followed by the interviewees' responses. The first ten responses are from BSc graduates who specialised in zoology and physiology and are currently completing their PGCE at the University of Cape Town, followed by ten responses from high school science students: -

*Does the labelling of fresh mammalian organs assist with the improvement of language skills in the classroom? Explain your view.*

#### BSc graduate 1

"In so far as it gets the students accustomed to using the names of the parts of the organs. This increases vocabulary, but I think it needs to be done in conjunction with reading text about the organs, or writing about it to improve language skills".

#### BSc graduate 2

"It does assist, since scientific language would best be remembered when associated with visual effects".



**BSc graduate 3**

"That depends on whether it is a group effort or not. Discussing a topic can lead to better understanding"

**BSc graduate 4**

"Yes. The connection between the written description and the actual physical organ or part of the organ will help the student to have a picture along with the word".

**BSc graduate 5**

"It can as it introduces the students to words that they probably have never seen or heard of before. They can associate a word with the real organ. It may be difficult for them to remember all the words".

*Do you think the labelling and viewing of the fresh mammalian organs will improve the students understanding of the anatomical structures? Explain.*

**BSc graduate 1**

"Yes. There is a picture to go along with the descriptions. The language of biology is being learned therefore making it easier to access the subject".

**BSc graduate 2**

"Most definitely. To physically touch the real specimen and to see it creates enthusiasm which results in more attention given, therefore more understanding. It gets imprinted in the mind better when it is a physical object that can be touched."

**BSc graduate 3**

"Yes. Labelling and viewing of these organs would give students a concrete basis and understanding. It is infinitely better to see and touch something concrete. Some religious and ethical aspects must be considered when using fresh organs".

**BSc graduate 4**

"Misunderstandings can occur if only the diagrams are used. Students get a better feel for the organ as a real structure. I think it is important that students see how a diagram can be drawn from a real organ".

**BSc graduate 5**

"The students learn not only from diagrams but from reality as well. Language is acquired through self-discovery".

*Do you think the labelling and viewing of the fresh animal organs will improve your understanding of the structures? Explain.*

**Student 1**

"One gets a much clearer perspective on how things look and function. This was my first time to have looked at a real brain. I found it interesting and enlightening to work with fresh specimens".

**Student 2**

"I think the practical was interesting as it brought the textbook to life. It is better than memorising the work. It showed me that the work we are doing has some relevance in reality".

**Student 3**

"Practical work is important as you remember things better and for longer. I think we should be allowed to do more hands-on practical work and maybe do the dissecting of the organs. Some of the structures on the organs is a bit more challenging to recognise".

**Student 4**

"Practical work is important as it gives one a broader insight by looking at the fresh organs. Trying to visualise the heart is not easy. I have seen the lung, heart, teeth and kidney before but I enjoyed labelling the organs".

#### Student 5

"Biology should be taught practically. It is easy to study because you remember what you have learnt in class. If you look at and label an organ you may be able to understand the structure and explain how it works".

#### Student 6

"This method of teaching gives you a visual side to the work. We are used to doing the theory. Experiencing each activity lets you learn more. There should be some time afterwards for the teacher to explain some more".

#### Student 7

"The demonstrations were shocking as I haven't seen them before, but it was very interesting. I prefer the practical work than the textbook. It would be really easy for me to understand the human body. I would like to see more".

#### Student 8

"This method (practical) is very good and you are able to participate and not sit there listening to a teacher until you eventually fall asleep. You get involved a lot. I think now I'll be able to remember the heart, kidney, teeth and the brain".

#### Student 9

I found it very interesting and it helped me to remember the stuff I learnt last year. I felt a bit weazy but it was alright. I enjoy biology so I enjoyed this task.

#### Student 10

I personally hate practical work but searching for the parts of the organs was more tempting. Today we turned boring biology into an enjoyable subject.

The respondents who attended the physical science test were asked by the second author (Inal) to write down their comments on a separate sheet that had an open ended question. The following are some of the comments that were made by the participants:

"I prefer this method to chalkboard".

"It becomes frustrating when you don't know the topic".

"These type of science lessons are very fun. I personally learn a lot more than notes on the board and textbook. This lesson was interesting and fun. I prefer this to teacher explaining it on the board and we writing it down".

"Science isn't one of my favourite subjects so I didn't want to do it at first, but after I did them I realised that it is not that bad after all".

"I think textbook definitely not enough. Hands-on must be associated to get the participation of the entire class".

"Although I didn't do science in Grade 10 it was an interesting exercise. It stays longer in one's mind if he/she is taught with this method. The best exercise was, for me, was shoes, because it is something we use everyday and people can relate to it".

"I don't take science but I think this is a very good method for people who are taking science".

"Although I don't do science I enjoyed this".

"Practical help understand science better, still we need explanations on the blackboard".

"I would like our teacher to use this in classroom".

"I think this is a good practical test. If we come to physics lab more often we can learn more about physics. When the teacher explains it on the board I can't picture it in my mind and I don't always understand".

In the below table the familiarity of the respondents and their marks on four items are given. No significant correlation has been found between familiarity of students and their marks on individual items or on the test as a whole.

When the marks of the respondents on labelling and demonstrating different types of mirrors and lenses are compared, no significant correlation has been found. That means the students who were successful on labelling mirrors may not necessarily be successful on lenses.

**Table 2: Scores of sub groups involved in the study (%).**

School/Institution code	10					20		30		40		
Grade	8	* 10	* 11	* 12	12	10	10	11	12	PGCE	Primary	Overall
Number of respondents (N)	30	17	22	15	15	19	28	26	32	9	24	237
Degree of familiarity with concave mirror (%)	32	27	36	30	50	45	48	50	41	56	58	
Concave mirror mark (mean)	73	47	82	60	100	90	7	31	78	100	96	66
Degree of familiarity with plane mirror (%)	61.7	35.3	61.4	50	70	73.7	64.3	55.8	51.6	94	73	
Plane mirror mark (mean)	83	71	96	67	100	100	21	30.8	84.4	100	100	74
Degree of familiarity with convex mirror (%)	33	26.5	36.4	30	56.7	47.4	42.9	48.1	36	56	340	
Convex mirror mark (mean)	77	53	82	53	100	90	7	3.8	71.9	100	96	62
Degree of familiarity with lenses (%)	68.3	64.7	72.7	63.3	80	84.2	44.6	40.4	31.3	83	85	
Real image by lens mark (mean)	3	24	5	13	13	32	21	15	31	100	13	20
Total score on four items (mean)	61	49	66	48	78	78	14	20	66	100	76	60

\* These are Biology only classes that do not do physical science



The statistical analysis of the data gathered on the practical physics test disclosed the following:

There was no significant difference between the scores of females and scores of males.

There was an appreciable difference between the scores of respondents who were English first language and second language speakers. The average score of English first language speakers was 70% and the average score of English second language speakers was 41%.

The figure 2 shows how the scores of English first language speakers and English second language speakers compare.

## Discussion



The majority of learners at the schools where this study was conducted agreed that fresh butcher's specimens should be displayed in the classroom for labelling and small group discussion of terminology during demonstrations. None of the respondents in this study objected to labelling the mammalian tissues. It must be remembered that these specimens could be used as food by some of the learners. It is possible that certain religious groups may object to the handling of animal organs.

It has also been observed that the learners were, in most cases, very enthusiastic and willing to take part. A number of participants admitted that when they are taught through practical experiences they understand and remember better. Some learners indicated that they are not willing to continue science because they find it too abstract. Therefore there may be cases where the learners memorise the concepts but never understand the meaning behind the 'wording' that is used for concepts.

The labelling of the fresh mammalian organs and identifying certain apparatus in biology and science could help students clarify the concepts in their minds. For example, if a learner is having difficulty in distinguishing between different types of mirrors and lenses he/she might have difficulty in comprehending a deeper discussion on these particular concepts. Therefore, showing the apparatus to the learners could make discussions in the classroom more *real*, enjoyable and understandable for the learners. It must also be noted that merely identifying these items of apparatus and parts of real specimens is a low level skill, yet very important to start with.

During the discussion of the results at the conference a number of experienced science and language educators agreed that it could be useful to show real apparatus and fresh organs in order to achieve a deeper understanding of the concepts by the learners.

As it reported in the results, especially in physics test there was found a significant difference between the total performance scores of English first language speakers and English second language speakers. This tells us that language proficiency of the learners could have an important influence on the performance scores and learning process of the learners.

The scores of participants were not compared according to geographical areas from which the learners originated. Such a comparison may reveal better clues on the results of the study i.e. whether or not the English second language speakers who are not at school in townships perform better.

## Conclusion

Asking a wide range of learners to label real-life apparatus and specimens in common use can provide an interesting and worthwhile form of continuous assessment in the classroom. In this investigation, very few practical items were difficult and most participants enjoyed a large measure of success. Practical work may be used to get the learners' attention and to improve their motivation and enthusiasm provided that the practical work is well-prepared and well-planned. In terms of the use of language in science classrooms, having real specimens and apparatus makes the science lessons more interesting and productive in terms of learning. This kind of practical assessment may give valuable information on the learning process as well if used periodically.

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(i)

Contents	Page
Development of Research and Teaching Capacity in Science, Technology and Mathematics Education in South Africa: Prospects and Challenges M. B. Ogunniyi	1
Practical Scientific Literacy: The Construction, Development and Classification of Sample Test Items in Physics A. Inal	8
Scientific Literacy: Contextual Realities and Postmodern Controversies M. B. Ogunniyi	17
Science Education for Lesotho Schools in the Year 2000: Concurrence between the Policy Priorities of Science Teachers and Science Students A. Moru	20
The attraction for Science: Why Grade 12 Girls in Five High Schools have chosen Science at School I. S. Qanya	26
Teachers Views on Mathematics, Mathematics Teaching and their Existing Practices L. Rossouw and E. Smith	37
How High School Biology Learners Prefer to be Assessed and Taught in Biology: A Comparison of the Ratings of Three Classes M. Asery	50
An Investigation into the Nature of Verbal Interactions During the Practical Training of Medical Technology Students M. C. Paulsen	59
The Impact of a Pentium Technology Option on Biology Students' Choice of A Multimedia Instructional Methodology: A Preliminary Study I. Demirtas	67
Exploring Methodological and Ethical Considerations in Reporting on Collaborative Assessment Practices in Physical Science in Four Secondary Schools N. J. Davies	75
Teacher Development in Large Classes M. Sadeck and A. Hendricks	80
Challenges for Promoting Quality and Equity in Mathematics, Science and Technology Education in Africa in the Next Millennium M. B. Ogunniyi	85

(ii)

## Practical Scientific Literacy – The Construction, Development and Classification of Sample Test Items in Physics

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### Purpose

The purpose of this initial study is to describe, illustrate and demonstrate the development and validation of 12 diagnostic practical items for testing the public understanding of the basic elements of electricity using actual apparatus. It is part of a much wider investigation with the following aims:

### Aims

The whole long-term study aims to investigate and compare sample performance skills, or levels of practical scientific and technological literacy, of senior high school physics students and their teachers. Secondly it aims to investigate whether there is a significant difference between the performance achievement of teachers and students on a longer test comprising thirty-four practical items. As a third aim, the development of the multiple intelligence of respondents specifically in the domain of practical scientific and technological manipulative literacy after White (1988), Gardner (1983) and Solomon (1996) will be explored, and corroborated or modified for a South African context.

In this short article, the first aim described above is the main focus of this research paper, together with methods for obtaining agreement, by consensus, on the classification of the items according to the categories of Solomon, White and Gardner.

### Theory

1. Gardner (1983) identified his theory of multiple intelligence challenging a single numerical IQ score. According to Gardner, components of intelligence can be identified separately, and some people develop some types of intelligences more than the other types of intelligences. Gardner conceptualized the human potential and mapped out the human abilities into seven intelligences as follows, with "G" standing for "Gardner" for the purpose of this paper:

- 1- Linguistic Intelligence (G ling)
- 2- Logical-Mathematical Intelligence (involved in eight items in the present study in 1999) (G lm)
- 3- Spatial Intelligence (involved in two items in the present study) (G spat)
- 4- Bodily-Kinesthetic Intelligence (involved in seven items in the present study) (G bk)
- 5- Musical Intelligence (G mus)
- 6- Interpersonal Intelligence (involved in all items in the present study) (G inter)
- 7- Intrapersonal Intelligence (involved in four items in the present study) (G intra)

In the current practical investigation the focus will be on the components of intelligence numbered 2 and 4 in particular (G lm and G bk)

2. White (1988) identified seven different elements of memories ("W" standing for "White") to describe the learning in science:

- 1- Strings (involved in nine items in the present study in 1999), (W string)
- 2- Propositions (involved in two items in the present study), (W prop)
- 3- Images (involved in four items in the present study), (W prop)
- 4- Episodes (involved in one item in the present study), (W epi)
- 5- Intellectual Skills (involved in seven items in the present study), (W int)
- 6- Motor Skills (involved in seven items in the present study), (W mot)
- 7- Cognitive Strategies (involved in three items in the present study), (W cog).

In the current practical investigation the focus will be on elements number 1, 5 and 6 (W string, W int and W mot)

3. Solomon (1996) has described a comprehensive theory of the multiple contents of the public understanding of science. In her paper "The development of life skills through Science and Technology Education for the 21<sup>st</sup> century", Solomon looks beyond the content of the school science curriculum, and beyond practical work in school laboratories. Among other things, she highlights the wider importance of science in everyday life and in social settings. She moves the context of learning science into the home; she engages economics and science; and she links the learning of science with the employment of trained technical experts in the labour market and vocational and core communication skills to prepare pupils for relevant careers needed by industrialists in a diversity of linguistic and cultural traditions. Finally, she focuses on science for the development of the individual pupil, encouraging the growth of independent learning skills such as creativity and curiosity.

For the purposes of this investigation, S stands for "Solomon", and her categories' symbols may be designated as follows:

- 1- Science for the Personal Development of the Individual (S I)
  - a- by enhancing his/her life skills (SI life)
  - b- by enhancing his/her vocational skills (SI voc)
  - c- by enhancing his/her communication skills (SI com)
  - d- by enhancing his/her citizenship skills (SI cit)
  - e- by enhancing his/her long-term values (SI val)
  - f- by enhancing his/her personal growth, feelings and emotions (SI grow)
- 1- Science as Requirement of a Specific Profession or Vocational Board/Body (SP)
- 2- Science for its own Rational Development (SR)
  - a- as a logically structured set of concepts, theories, processes, skills, evidence, knowledge and limitations (SR con).
  - b- as a development of historical events (SR hist)
- 4- The Humanistic Utility of Science (SH)
  - a- for societies' needs (SH soc)
  - b- for the economic development of a nation (SHE) with a specific reference to
    - i. better health (SHE health)
    - ii. the environment (SHE envir)
    - iii. social reconstruction (SHE recon)
    - iv. science for the work place (SHE work)
    - v. ethical dilemma (SHE ethic)
    - vi. the international future competitive edge (SHE compet)
    - vii. mobilization for informed, motivated and substantive social change (SHE change)

- viii. cultural transmission of knowledge (SHE cult)
- ix. adaptable, novel retraining of the workforce (SHE retrain)

For the purpose of this investigation, the categories of Solomon's paradigm will be used to label clusters or groups of practical test items on a given topic in physics. This is because Solomon's categories are more widely encompassing, and more general, than the more specific categories advocated by White and Gardner. Thus, they can be used to characterize tests as a whole, being applicable to every individual item within a given practical test.

Lock (1989) also introduced an assessment framework for practical work skills appropriate to pupils of secondary school age (11-18 years). This assessment framework was validated for him by a panel of ten experienced science educators.

He used this assessment framework to study the relationship between the component skills. The practical skills concerned were:

- 1- Observation:
  - Observe accurately (correspondence between the record and the event as seen by a supervisor)
  - Read instruments correctly
- 1□ Manipulation
  - Set up apparatus appropriately
  - Use apparatus/materials appropriately
  - Work accurately/systematically
  - Carry out operations in correct sequence/follow instructions
- 2□ Interpretation
  - Interpret observations
  - Interpret numerical data/diagrams
  - Indication of source of errors (material and methods)
  - Ability to calculate
  - Make predictions
- 3□ Planning
  - Devise a simple experimental procedure (including selection of apparatus, measuring instruments)
  - Use of controls/trial experiments/observations
  - Problem-solving
- 4□ Report
  - Use scientific language (written/verbal)
  - Arrange/organise the data/observations
  - Accuracy with which procedure reported
- 5□ Self-reliance
  - Asking for assistance and for conformation of approach

Lock concluded that the skills of interpretation and planning are strongly related to each other. Thus, another paradigm for classifying items testing practical scientific literacy could be developed from Lock's framework. These elements could be designed as 'L obs', 'L man', 'L int', 'L plan', 'L report' and 'L self', but in this preliminary paper this classification system was not trialled with the groups of pilot study teachers, due to shortage of time.

#### The aim and nature of practical work

Okebukola & Ogunniyi (1984:883) recommend that, to promote laboratory skills, students should be allowed to interact with themselves on a competitive basis.

Chacko (1997) categorises practical work as 'Teacher Centered' and 'Student Centered', and he prioritises twenty aims, as follows:

- 1□ As a creative activity.
- 2□ To make phenomena more real through experience.
- 3□ To help remembering facts and principles.
- 4□ To practice seeing problems and seeking ways to solve them.
- 5□ To indicate the industrial aspects of science.
- 6□ To promote a logical reasoning method of thought.
- 7□ To encourage accurate observation and description.
- 8□ For finding facts and arriving at new principles.
- 9□ To become able to comprehend and carry out instructions.
- 10□ To elucidate theoretical work as an aid to comprehension.
- 11□ To develop self-reliance.
- 12□ To arouse and maintain interest.
- 13□ To develop an ability to communicate.
- 14□ To develop an ability to co-operate.
- 15□ To develop certain disciplined attitudes.
- 16□ To develop specific manipulative skills.
- 17□ To verify facts and principles already taught.
- 18□ To develop a critical attitude.
- 19□ To give experience in standard techniques.
- 20□ To prepare the students for practical examinations.

In this paper the focus is mainly on aims numbered 2, 4, 7, 9, 17 and 20.

#### Methodology

Okebukola & Ogunniyi (1984:883) make four recommendation for carrying out laboratory work in groups. These are:

- 1□ Cooperative laboratory work should be used by science teachers to improve the cognitive achievement level of students in science.
  - 2□ Encouraging high ability students to work together in a group appears to be a good approach to improving their achievement levels.
  - 3□ Rather than allow low ability students to work together in a group, allowing interaction with some average, and high ability students in a mixed ability group will lead to improved performance of the low ability students.
  - 4□ Mixed or heterogeneous ability grouping for cooperative work in the laboratory has more facilitative effect on the achievement of low achievers than the competitive goal structure.
- Hence this rationale for group laboratory investigation was adopted in the present study.

#### Pilot trial no.1

In the first pilot trial in April 1999, which lasted 25 minutes, four science teachers-in-training were conducted through the items to clarify the wording of the instructions. Items were selected on the basis of their being fundamental to a knowledge of practical science and technologies as agreed by a panel of experienced physics teachers, e.g. Ogunniyi (1999). All respondents were free to discuss their responses with each other. Then each respondent wrote down his/her own responses individually.

The first pilot study comprised 27 basic practical physics items. Each item contained a simple instruction with some elementary apparatus presented on mounted display boards with a paper background.

#### Pilot trial no.2

The second pilot trial, which took 50 minutes, was conducted with eight science teachers and academicians at the University of the Western Cape in May 1999 using twelve practical physics items on the topic "electricity". Each item contained apparatus and a simple written instruction, the wording of which had been revised after pilot no.1.

The seminar had two parts: practical and theory. In the practical part each attendant had an answer sheet on which to write responses and comments, the latter being more important than the former. The practical section took about thirty minutes.

In the theory part, a summary of the learning theories of White, Gardner and Solomon, on white, green and yellow sheets respectively, was supplied for the participants. On each white page a different element of White's learning theory was provided. The same was done with green pages for the theory of Gardner and yellow pages for Solomon's theory. The attendants then classified each item by group consensus, according to the above mentioned learning theories, for a period of approximately twenty minutes.

#### Pilot trial no.3

The third pilot trial, which took 50 minutes, was conducted with fourteen grade ten, eleven and twelve students from a historically disadvantaged physical science class at Oscar Mpeta High School in May 1999 using eighteen practical physics items. Items had been modified or re-worded, if necessary, after pilot trial no.2, and each one comprised a simple piece of apparatus and a simple written instruction, which the students were required to evaluate for their usefulness as possible learning materials for their school.

The fourteen students were divided into four groups, two of which involved three students and the other two groups involved four students. Each group went through the items, and the learners discussed the items among each other. Each student used an answer sheet to write down responses and evaluations about the test items. The group discussion of the items among each group was encouraged during the administration of the program, since the purpose of the exercise was to evaluate the clarity, relevance and utility of the new materials themselves. It was stressed that the students were not being evaluated, since some of the instructional materials were new in science education.

#### Preliminary Findings

##### Pilot trial no.1

In the first pilot trial the science teachers-in-training showed that some of the instructions for the items were not clear in wording or contained faulty apparatus. According to the respondents six of the items required re-wording, and for four items the working of the apparatus itself needed to be checked. Some examples of re-wording were as follows:

**Example 1.** Item 11-b read: "How many of these tiny light globes do you think you would need for your kitchen in your home?". It was changed to read: "How many of these tiny light globes all glowing together do you think would give the same brightness as the light globe in your refrigerator?".

**Example 2.** Item 16 read "Look at the ammeter and read the current when the ammeter needle is at five".

It was changed to read "Look at the ammeter and write down the current when the ammeter needle is at the red line drawn on the ammeter".

**Example 3.** Item 18 read: "Look at the *galvanometer* and the adjustable resistance. Adjust the *galvanometer* to measure the resistance. Then estimate the maximum value of the adjustable resistance". In this item the word "*galvanometer*" was changed to "*multimeter*".

**Example 4.** Item 19-a read: "Look at the circuit and point the direction of the current going through the circuit". In this part the word "current" was changed to "conventional current". In item 19-d "Now check it with the ammeter" has been added to make students first estimate the amount of the current before they check it with the ammeter.

#### Pilot trial no.2

With experienced science teachers at the University of the Western Cape, the aim was not to derive the physics answers from the participating attendants. The purpose of the evaluation was to obtain a consensus validation of the re-worded items, one by one, and their suggestions for improving the validity of the whole test. Comments raised by the attendants are discussed below.

One of the ideas that emerged during the discussion session was the need to reduce the number of items. They suggested that instead of having a large number of items from different topics, the items presented could be chosen from one topic only. Thus the need has arisen to derive a series of separate tests of practical/manipulative scientific technological literacy for the topics of electricity, optics, mechanics, magnetism, electrostatics, etc. individually.

The importance of giving explicit instructions for each item was emphasized by one of the attendants.

Another participant stated that this type of research and evaluation is more qualitative than quantitative - in this pilot study phase of refining and perfecting individual test items - prior to mass testing later with validated test items. They also recommended that teachers should explain the solutions and some core points about the practical items after students had solved them. In this way, while testing their practical scientific literacy the study/investigation could also teach students additional information about apparatus and equipment.

Participants asked whether we normally did any pre-test of students' level of prior knowledge. Another idea that was raised during the discussions was to conduct the test after teaching the learners the related topics. They also suggested that the materials be evaluated in schools located in different areas, and that the critiques of the materials be compared with each other.

After the practical part of the pilot trial ended, the participants commenced the more theoretical section in which they classified the items by consensus. In this section the attendants classified the items as follows:

- Item 10:** W string, W prop, W int, W cog,  
G lm, G ling  
S H, S V
- Item 11:** W int, W string, W prop, W cog, W imag, W epi  
G lm, G ling, G inter  
S H, S V,
- Item 12:** W int, W string, W prop, W cog, W imag, W epi, W mot  
G ling, G lm, G bk, G spat,

- Item 13: W int, W string, W prop, W cog, W imag W epi, W mot  
G ling, G lm, G bk, G spat, G intra
- Item 14: W string, W prop, W imag, W epi, W int, W mot  
G ling, G lm, G spat,  
SH, SI, SR
- Item 15: not attended
- Item 16: W string, W imag, W int, W cog  
G ling, G lm, G spat, G intra
- Item 17: W imag,  
G ling, G inter  
SV

#### Pilot trial no.3

The third evaluation of the twice-modified materials occurred with English second language high school physical science students whose home language is Xhosa.

Allotting each item one point for a correct answer, the average score out of 18 recorded by the students in this study was 4,6. The range of scores recorded was from 1 to 7,5 out of 18.

In general the physical science students were familiar with the items of apparatus that are used every day. The ones that require previous laboratory experience were more difficult for the students to handle and carry out demonstrations, such as the voltmeter, the ammeter, and especially the galvanometer and the multimeter.

Another finding that emerged from this trial was that the students' theoretical knowledge was incomplete. Consequently they had difficulty in handling some of the apparatus. The students were unfamiliar with details of some of the apparatus, such as signs, units and connections of the equipment.

As a result of the students' comments and suggestions, some of the practical items have undergone a third revision; for example:

Item 12: The item has been amended as " ..... (terminals plus to minus, minus to plus, ....) ..... Point to one of the combinations 1, 2, 3 and 4 of the batteries that will .....when connected to the red and the black wires."

Item 16: The item has been amended as " Look at the ammeter. Assume it is connected to a circuit which includes the diagram. Write down the current when the ammeter needle is at the red line drawn on the ammeter".

Item 18: The item has been amended as " ..... Then estimate the maximum value of the adjustable resistance in OHMS,  $\Omega$ ."

#### Respondents' Evaluation of the Programme as a Whole

Commenting on the practical exercise as a whole, the eleven most constructive qualitative remarks recorded from participants during the three pilot trials were as follows:

- 1□ The instructions must be as clear as possible and must not be misleading.
- 2□ The apparatus must be appropriate and simple.  
Only the necessary apparatus must be supplied without any missing item or detail.
- 3□ The prior knowledge of the learners must be considered. The items must be at the levels of the
- 4□ learners' knowledge.

- 5□ The learners must be observed very carefully during the administration of the programme. Everything they say and do must be recorded in order to perfect each item as a credible test of practical scientific literacy during the pilot trials.
- 6□ Strange items that the students might have never come across must not be involved in the programme.
- 7□ The target group for the items must be stated clearly.
- 8□ The response that is expected from the learner must be identified before the administration of the programme.
- 9□ The number of the students in one group must not be more than three, and every member of the group must be given the opportunity to handle the apparatus.
- 10□ The space supplied for each item must be arranged so that the learners can carry out the demonstrations and experiments.
- 11□ The theoretical knowledge which is necessary for each item must also be identified.

The most serious shortcomings of the programme in its initial phases were described by various participant as:

- Some of the instructions were ambiguous and misleading.
- Some items of apparatus were not clear.
- The answer sheet was incomplete and not prepared well.
- During the administration of the test, the number of learners in one group was large.
- Some signs and symbols that the students did know, were used.

Nevertheless, all lecturers, teachers, students and pupils who participated in the three trials of the development of the materials (and in a fourth trial at an independent school) described the exercise as "well worthwhile; to be encouraged enthusiastically; very effective learning", etc.

#### Discussion

Following the first pilot trial, six of the practical items on the topic electricity were reworded, and the apparatus of four of these items was checked for technical accuracy and reliability of function.

The second pilot trial was a good experience for evaluating both the theoretical and practical aspects of the programme, and to have the test items validated by experienced science teachers and academicians. As a result of the second pilot trial, some aspects of the research were clarified e.g. the aim, the target group, the methodology of the research (qualitative or quantitative), and the procedure for administration of the test. However, respondents did not have time to classify five of the items (15, 18, 19, 20 and 21). Using the consensus classification of seven items on the topic 'electricity', the learning theory of White was found to be the most relevant and applicable theory of the three. Although the learning theory of Solomon is wider, the attendants did not see her theory as being of focused relevance to the specific physics items used in the second pilot trial. One disadvantage in this evaluation exercise was that the participants did not have enough time to discuss the learning theories sufficiently among themselves.

One of the most important outcomes of this trial was that the answer sheet (item evaluation sheet) was refined and prepared again. In the original answer page the responses that were expected from the respondents were not clear and misleading.

In the future evaluations the alternative assessment framework of Lock (1989), the specific outcomes of Outcomes Based Education for natural sciences (1997) and the sub-systems of thinking advocated by Frans (1992) will be used to try to classify the practical items.



In the third pilot trial it was possible to evaluate how well the items were perceived by the high school students for whom English is a second language. During the administration of the practical program items I observed that the students were not always certain how to relate their theoretical knowledge to some of the practical cases. Their theoretical knowledge also seemed to be incomplete for certain topics, which they might not yet have reached in the syllabus.

Since English is a second language for these students it had an impact on their understanding of and responses to some of the items so the wording of three items, items 12, 16 and 18, will be amended for new trials in the future.

All of the students participating in this pilot trial were not at the same grade. Therefore some of the students may have not covered some of the topics. This might have caused some students to give incomplete responses to the items.

### Conclusion

It is concluded that the formulation, design and production of useful, comprehensible, credible, clear and interesting diagnostic materials for assessing students' levels of practical scientific literacy is a process which may involve more than half a dozen successive trials and modifications. Not only must they be theoretically sound and coherent, but items must be useful to, and acceptable by a wide range of students in a very diverse set of teaching conditions in the new and developing South Africa.

### Acknowledgements

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Also acknowledged with thanks are the helpful insights into the development of the materials offered by Professor M. B. Ogunniyi and his research students at the University of the Western Cape.

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# APPENDIX

## 2

Samples of the initially developed 33 practical  
task items' photographs and wording

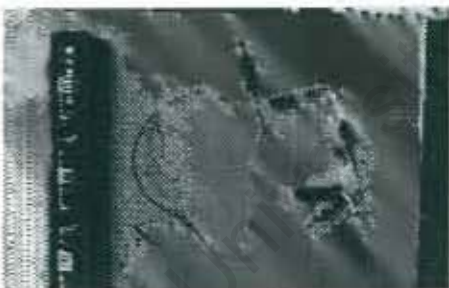
PHOTOGRAPHS AND WORDING OF SAMPLE ITEMS THAT WERE INVOLVED IN PHASE 1 OF THE INVESTIGATION



Pick up the label/s that can be measured or calculated using only this device.



Give a sudden push to the trolley towards right on the table. At the instant that the trolley passes the line, pick up the arrow and point the *direction* of the NET (overall) force on the trolley. (Indicate your response on the answer sheet)



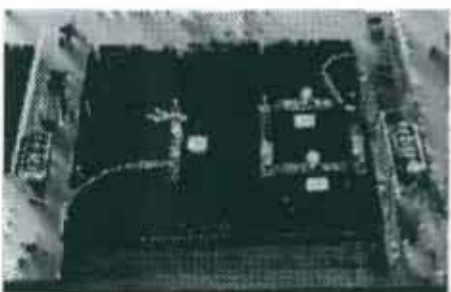
Look at the three cells in a row, connected in series. Identify the one cell which is "flat" by checking each one with the light globe.



Look at the open circuit. Make the necessary connections and make the light burn. Then change the brightness of the light globe



Look at the multimeter and the adjustable resistance. Adjust the multimeter to measure the resistance. Then estimate the maximum value of the adjustable resistance in OHMS ( $\Omega$ ).



Look at two circuits.

Check the brightness of the three bulbs when both circuits are completed by connecting the battery ( $1>2>3$ ,  $1>2=3$  etc.). Then describe your observation.



Look at the spectacles. Point to the concave surface of the lens.



Look at the three double convex and a double concave lense.

- a- Decide on the one which has the *longest* focal length.
- b- Decide on the lens which will set *fire* to a piece of paper the quickest using sunlight.

# APPENDIX

## 3

Samples of the audio-captured  
conversations of the participants

**Samples of Audio captured comments by secondary and tertiary level participants (1999 July - December)**

- 1- Electricity items were difficult. I have forgotten what I have learnt in school.
- 2- I can see the need for having hands-on experience.
- 3- These activities can be linked to everyday life
- 4- Make some of the questions clearer
- 5- I need information on all these.
- 6- Apparatus must be working well.
- 7- I found electricity items difficult because of lack of knowledge.
- 8- It is great to do hands-on activities
- 9- This is something which is so important in teaching and learning
- 10- This is a good way of planning and organizing lessons in outcomes based education
- 11- I need to use this method of teaching when I go to school though there is lack of work done before hand.
- 12- I realized that this is a very good way of teaching
- 13- This is cool (about the electric circuit)
- 14- Trolley is moving towards right so there must be a force in this direction.
- 15- If this side pushes North it must be South because opposite charges attract each other.
- 16- You need an ammeter and a voltmeter to measure the resistance.
- 17- (When comparing brightness of two bulbs in parallel with a single bulb) There are two bulbs here so they will be less bright.
- 18- Gravitation is downwards so it must be lifted up to do work against gravity.
- 19-  $g$  is normally  $10 \text{ m/s}^2$  so

# APPENDIX

## 4

Participants' (high school learners') hand  
written comments

Name: ZOLEKA BEN GU

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in classroom? Should it be left out of classroom practice?

I think it is right because  
you learn about something.  
you see is in front of you  
I didn't find it difficult. I think  
it can be used in classroom -  
because if you teach about  
something you didn't see you -  
find it difficult because you can't  
see it. No, it must be done in -  
class with all students so that  
they can see.

### Comments:

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in lessons? Should it be left out of classroom practice?

I feel that this kind of practice should be done more often  
so that we can know <sup>what</sup> ~~what~~ is going on. No, I did not find  
it difficult at all. I strongly put emphasis on this because  
I feel this will give us a clearer view on what we are  
doing in class. No, it should not be left out of classroom  
practice. I am very happy we have done something  
like this today because I now have a clearer view on  
my physics.

INSAN SHUK. Phai.



The Science methods, I think, were very good.

This method makes it exciting and interesting to learn as well as fun. The text book method makes science boring because all you do is read and carry out ~~explanat~~ experiments. We wouldn't need the textbook method if we had more teaching that works with the apparatus as you go along. Working with electric wires is exciting and you can actually see for yourself if there really is electricity because you are doing the experiment. With these methods it really makes you want to do science because you are doing experiments. This can help us in the future if you wanted to be an electrician or something because you'll know which wire goes where. You could even design your own appliance for home, work or something else. It would really help us to learn more and to be interested in science.

#### Comments

Physical Science is a subject that involves a lot of hard work and brain teasing and you have to really think about what you do, but when you find the solution of a certain problem, or the answer of a task, you feel good about yourself. I enjoy working with live wire and I prefer to try and prove points myself than to just be told that something is true, and it is always easier to keep your concentration when you're working with the real thing. I do think that science is very important if you ever want to design any type of object/s as it teaches you the way things work and the formula of certain substances. It is a very enjoyable way of

### Comments

The science part of the practical was quite interesting, even though I didn't choose science for Gr 10 I enjoyed it.

It is good some of the exercises you were able to pick up the objects & measure certain objects, if you do that it stays in your memory more than if someone had just told the information to you. It is a very good teaching method & properly the one I learn the most from.

The best ~~ex~~ exercise or question for me was the shoe, sneaker because it is a everyday object & people can relate to it well. The scientific equipment were not very understandable for me. Overall it was interesting & informative.

### Comments

Well, I don't really have much to say as, I don't do Science and that is because I don't enjoy it and it doesn't interest me.

So, when I was told that I had to look and work on the Science section, I was not very pleased! But, in the end I managed to do most of the exercises, some were easy - others needed a little more thought, however I attempted them.

If I was a science student, then I would say that the display and questions are a good teaching / learning method.

I can't say much except for good luck for the future & I hope this works for all the Science Students.

Name: Nobongani Mpando

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in classroom? Should it be left out of classroom practice?

I think it is right to learn about that, because I learn more with my group. I see something that I didn't know. And I point it. I never lose it. Any way I should learn in Classroom but now I see in front of it.

Name: C. ...

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in classroom? Should it be left out of classroom practice?

I think it is right because a learn, and it is not difficult at all. It shouldn't be let up in class and you see in front of you in our classrooms, and they need to practise because if you say is difficult in your head, they are not change, and you must prove because they have in front of yours in classes. They also need you to read it.

Name : Stemele Andisa

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in classroom? Should it be left out of classroom practice?

I think it was very important  
because we learned a lot.  
If you don't mind to come  
<sup>again</sup>  
~~to come~~ you can come  
as long as you will teach us.  
It should stay in class-  
room because we understan  
understand very easy.  
Thanks.

Name : Simplice Nkomo

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in classroom? Should it be left out of classroom practice?

It should be used in class. I've learnt a  
lot about these experiments. I wish you  
can come again or invite us to do  
another experiments that we were never  
told of. And we hope you can supply  
us as well with other helping textbooks that  
will be more easier than the ones we have,  
or if you are kind enough you can organise  
science project that will help us know  
what we learned at class. To me I wish  
my requirement can be fulfilled. Thanks  
for everything you have shared us today.

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in classroom? Should it be left out of classroom practice?

No it was not difficult. Some of the experiments you can with your naked eye, yes I will be glad because we will know something and it will be easy to understand. No they can't be out of classroom because they are strictly for the school instruments.

Name : Nondumiso Cibi

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in classroom? Should it be left out of classroom practice?

This is a wonderful practice it is a fun practice. It is not difficult it is easy and fun. I think it should be used in the classroom for us to prove how we understood the work when we were taught. No it should not be left out of classroom practice because it gives us joy to practice.

### Comments:

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in lessons? Should it be left out of classroom practice?

I really enjoyed myself. It was a fun and more exciting than boring class. You get a better understanding because you are learning first hand. It was not difficult at all. I think it should be used in class.

### Comments:

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in lessons? Should it be left out of classroom practice?

Some of these were a bit difficult, but that gave me a chance to think.

I think its a good way of learning and it can be used in classrooms. Lets you know what you dealing with.

### Comments:

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in lessons? Should it be left out of classroom practice?

I think it is very interesting and many people can learn by doing experiment/practicals. My practical was fairly easy, considering the fact that such ~~an~~ experiments ~~is not~~ are not my strong points.

I would prefer experiments to be part of our lessons in class. It would surely get more attention rather than a page with a diagram. The experiments were not difficult & easy to understand

**Comments:**

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in lessons? Should it be left out of classroom practice?

I think it was quite an interesting experience and it would be a good idea to introduce it in a classroom lesson. It was not that difficult and I'm sure with a bit of help most people would have the ability to complete such an experiment / practice. It would also be a good thing for the classroom.

**Comments:**

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in lessons? Should it be left out of classroom practice?

I did not find it that difficult. I think it should be used so that the pupils learning the work can actually experience what they are learning.

Thank You!!

Name : \_\_\_\_\_

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in classroom? Should it be left out of classroom practice?

I think they are needed desperately because we can learn many things from the practical and that learning about something you have seen you can never ever forget it. I think that practical must take place of each and every lesson if that lesson have some practicals.

Name : SIZWE

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in classroom? Should it be left out of classroom practice?

It was nice to learn about these things because we experienced something that we didn't experience before because in our schools we have a lack of stuff which is used in Science we are not going to the labs because we don't that kind of stuff but it was not too difficult to work with these things. So I say thank you.



Name : \_\_\_\_\_

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in classroom? Should it be left out of classroom practice?

It was nice to test my knowledge because things like this at school we never done them. This practice is very good cause it help me to see what I've learnt in the past. It was difficult because it was my first time doing this practical. It must be useful in the classroom to help us.

Name : BONGANI Mbelweni Girl

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in classroom? Should it be left out of classroom practice?

I think to me is give a lot of knowledge and give train think. To me is right. Also right to do this things practical because some of us don't do not know these things or when you talk about rhetorical so, when you do practical is better and right. If teacher can teach like so or practical is right and no student can fail. It give us a potential to not about this experience.

Name : \_\_\_\_\_

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in classroom? Should it be left out of classroom practice?

It was very fun and exciting although we are not used in practical test experience at school we always given task in notes reading and classwork and Homeworks only thanks "please give us more practical test so that we get familiar with this practical experience please come back again and again."

Name : Andiswa Sikit

You have gone through a practical test experience. Please give your opinions and feelings about this kind of practice. Did you find it difficult? Should/can it be used in classroom? Should it be left out of classroom practice?

No, it wasn't that difficult because we have done the things in school, but we didn't do it practical it was just theory. Yes, it should be in the classroom because when you are doing something practical you won't forget it but theory it's easy to forget. And I think it should be done more often so that we can learn more on the practical.

# APPENDIX

## 5

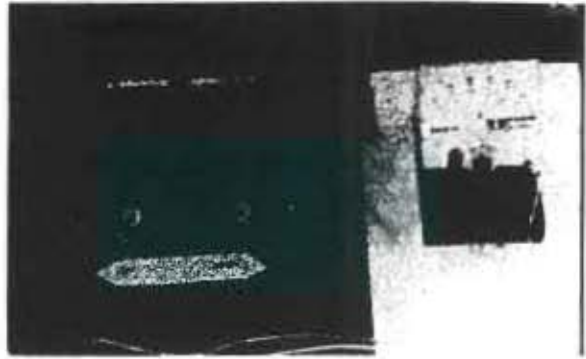
Examples of the re-wording of some of the items that were done during pilot studies

# ITEM 19

Look at the circuit given

- Point the direction of the current going through the circuit
- Connect the ammeter and read the current going through point A.
- Guess how much current goes through point B

~~107-10000000~~



(1) U.C.T.

a- direction of the conventional current

same

(2) X.G.C.H.S

"d- Now check it with the ammeter's part was added.

same

1. d. U.C.T.

no change

same

(O.S. on of p. 10)

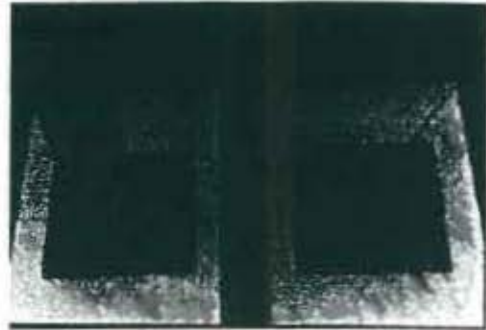
— not conducted —

same

University of Cape Town

# ITEM 2

Measure the volume of the object by using the apparatus you have. (~~Add the weight of the~~)



Measure you have  
Add the weight of the  
measurement.

TRIAL 1  
(U L T.)

No change was made.

TRIAL 2  
(SE U L T. H D)

Not conducted

TRIAL 3  
(U L T.)

No change was made

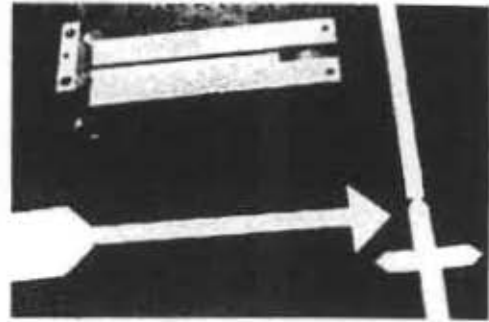
TRIAL 4  
(SE U L T. H D)



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# ITEM 4

Push the trolley towards right on the table. At the instant that the trolley passes the line past the camera and point the direction of the net (vertical) force on the trolley.



TRIAL 1  
ULT

Force is sudden push to the trolley

SAME

TRIAL 2  
2.5 m/s

No change

SAME

TRIAL 3  
1 m/s

Not conducted

SAME

TRIAL 4  
Come up to  
1.2

No change

SAME

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# ITEM 7

Look at three plastic strips.  
 a) Pick up two that will attract each other when they are rubbed with silk  
 b) Pick up two that will attract each other when one is rubbed with silk and the other by your hair



U.C.T

Part c "Then carry out both demonstrations" was omitted

SAME

St George's  
G.H.S

... strips (different colours made of different materials which are charged oppositely when rubbed with the same material)

Strips were to be numbered

U.W.C

Not conducted

SAME

Don-Mphah  
H.S

No charge was made

SAME

# ITEM 8

Look at the magnets and the compass. Identify the ~~North Pole~~ North Pole of each magnet by using the compass given to you.



U.C.T.

each magnet and  
compass

One compass was added.

St. George's  
G.H.S.

S

U.W.C.

S

Osaka-Matsu  
H.S.

S

University of Cape Town



# ITEM 11

Read the information on the tiny light globe.

a) If the battery is 3.0 volts with a direct current of 0.2 amp enters the wattage of the light bulb.

b) How many of these tiny light globes will glimmer together do you think would give the same brightness as the light globe in your ~~reference~~ kitchen?



1) UCT

b) as the light globe in your reference

— no change —

— original —

— the light bulb was changed —

2) St G G H-3

3) U.M.C

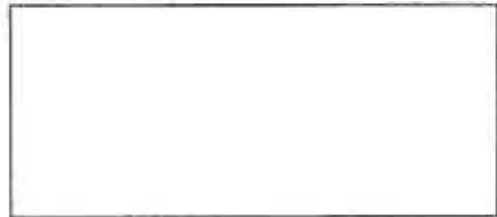
It is emphasized that a calculator could be used.

— no change —

— Accelerator is released —

— no change —

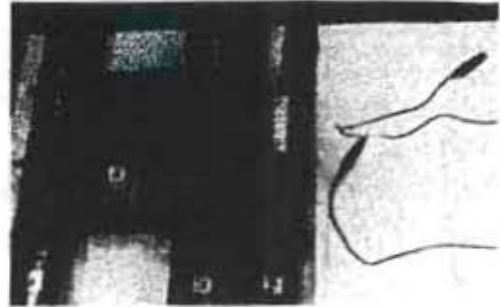
4) Osc. Mech



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# ITEM 12

Look at the four different arrangement of batteries (plus to minus, minus to plus, plus to plus etc.) and the bulbs.  
 Point to the one of the four combinations that will allow the bulbs to glow for the longest period of time when connected to red and black wires.



1) C.L.T

no change

Scene

2) S.E.G.G.H.B.

no change

Scene

3) U.W.K

no change

Scene

4) One of the

--- (terminals plus -  
 - four combinations of batteries  
 (1, 2, 3, 4) --- to glow the  
 when connected to the red  
 and the black wires

Scene

# APPENDIX

## 6

Copies of coloured classification cards that were used by the educators and academics to classify the items

#### 4- Episodes

According to White “episodes are our records of experience, memories of events and occurrences we took part in or witnessed”. Only the episodes we bring to memory are available to us for a long time. An episode can be a real event, transformed event or an imagined event.

Please tick the relevant option for each item considering the definition of **Episodes**.

Item #	1	2	3	4	5	6	7	8	9	10
More				X						X
Average			X		X	X				
Less	X	X					X	X	X	
Irrelevant										





He used this assessment framework to study the relationship between the component skills. The practical skills concerned were:

1- Observation:

- |                     |   |   |   |   |   |   |   |   |   |    |
|---------------------|---|---|---|---|---|---|---|---|---|----|
| Item #              | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Degree of relevance | 3 | 3 | 3 | 2 | 2 | 2 | 3 | 3 | 3 | 3  |

- Set up apparatus appropriately
- Use apparatus/materials appropriately
- Work accurately/systematically
- Carry out operations in correct sequence/follow instructions

Item #	1	2	3	4	5	6	7	8	9	10
Degree of reduction	3	2	3	1	2	3	3	3	3	3

- Interpret observations
- Interpret numerical data/diagrams
- Indication of source of errors (material and methods)
- Ability to calculate
- Make predictions

Item #	1	2	3	4	5	6	7	8	9	10
Degree of infection	2	2	3	3	2	2	2	3	2	2

- Devise a simple experimental procedure (including selection of apparatus, measuring instruments)
- Use of controls/trial experiments/observations
- Problem-solving

Item #	1	2	3	4	5	6	7	8	9	10
Degree of importance	3	2	3	1	2	2	2	2	2	3

- Use scientific language (written/verbal)
- Arrange/organise the data/observations
- Accuracy with which procedure reported

Item #	1	2	3	4	5	6	7	8	9	10
Degree of relevance	2	1	3	1	2	3	2	3	1	2

- Asking for assistance and for conformation of approach

Item #	1	2	3	4	5	6	7	8	9	10
Degree of relevance	<del>X</del>	X	<del>X</del>	X	<del>X</del>	<del>X</del>	<del>X</del>	<del>X</del>	X	<del>X</del>

#### 4-The Humanistic Utility of Science

- a- for societies' needs
- b- for the economic development of a nation with a specific reference to
  - i- better health
  - ii- the environment
  - iii- social reconstruction
  - iv- science for the work place
  - v- ethical dilemmas
  - vi- the international future competitive edge
  - vii- mobilisation for informed, motivated and substantive social change
  - viii- cultural transmission of knowledge
  - ix- adaptable, novel retraining of the workforce

Please tick the relevant option for each item considering the definition of SH.

[illegible]

# APPENDIX

## 7

Further comments on individual items and  
on the programme in general by the  
educators and the academics



Samples of comments that were made by science educators and academics at various seminar series and conferences (1999 – 2001)

What is the main research question?

Your test focus question is probably one framed more imaginatively in terms of **GRADED PROCESS SKILL ATTAINMENT** instead of one framed in terms of "give the correct tightly controlled answers, which approach is too like Nuffield.

Frame your focus question in terms of measuring the extent of attainment of a process skill. Devise a graded process skill on a scale of 1 to 4 for each lens (concave and convex) not just yes/no, right/wrong response etc.

Discuss merits and demerits of school practical work. Research is so inconclusive that many countries in the world are now cancelling practical work altogether, especially in schools in poor regions. In Metriculation Exam papers the percentage of questions about practical work has been reduced from 20% to 15% etc.

Discuss the Government's policy on actually providing materials for practical work for all schools. Quote the documents on actual provision, not just on desirable policy or intention to translate words into resources. Describe all the difficulties of actual implementation in practice by government departments. If it is government policy to teach science in schools only theoretically with the ultimate goal attainable only later in implementation then discuss this.

Discuss the merits of pupil practical work versus teacher demonstration e.g. where classes of 50-80 pupils exist, where there is no refrigerator. No school money for equipment.

Skills to be measured by each item should be identified.

Learners should perform the activities individually if you want to measure their individual performance.

The following items were items in electricity:

Item 10. It needs to be rephrased

Item 11. This item should state that a calculator is allowed. The information on the bulb itself is small and not legible enough. One person stated that the learners may not have any idea about how bright the light in the refrigerator glows.

Item 15. We must label the ends of the circuit that must be connected to the batteries. One participant wrote down "what is the purpose of this investigation?"

Item 16. We may need to replace the circuit figure with a real circuit.

Item 18. One respondent said that the students could be allowed to connect the multimeter, and that is normally what I do in the administration period of the test.

Item 19. One said that part 'c' "Now check it with the ammeter" could confuse the students because students may think that they have already measured the current and now they should find another value.

Item 21. The light bulbs must be identical.